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an engineering analysis of cargo handling

UNIVERSITY OF CALIFORNIA, LOS ANGELES

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AN ENGINEERING ANALYSIS OF CARGO HANDLING

An engineering analysis of the loading and unloading of ships that can be used as the basis for both general and specific revisions of the cargo-handling system.

Department of Engineering
University of California
Los Angeles

FOREWORD

The research described in this report, "An Engineering Analysis of Cargo Handling," was conducted under the supervision and technical responsibility of R. R. O'Neill in the Department of Engineering, University of California, Los Angeles. L. M. K. Boelter is chairman of the department.

This research was conducted under the sponsorship of the Department of the Navy, Office of Naval Research, and the Department of Commerce, Maritime Administration.

R R O'Neill

R. R. O'Neill
Project Leader

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Walter C. Hurty

Walter C. Hurty
Vice-Chairman
Department of Engineering

October, 1953

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The following staff members contributed to the project during the period covered by this report: A. Abruzzi, J. D. Carrabino, R. J. Carrington, J. E. Dougherty, S. I. Firstman, E. W. Greenstadt, W. A. Hall, H. M. Hughes, A. R. Marks, R. L. Mellinger, H. Kr. Mörck, R. R. O'Neill (Project Leader), A. Rosenbloom, C. J. Vogt, J. K. Weinstock, and J. F. Welsh.

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INTRODUCTION

Despite the progress made by the shipping industry over the years, one of its key operations, cargo handling, has remained essentially the same since the days of the wooden ships. Cargo is still taken piece by piece and hoisted with a hook up and over the side of a ship and into the hold. Consequently, this operation remains a perennial bottleneck.

For example, immediately following World War II larger and faster cargo ships were put into service. Tonnage figures, however, did not reflect this increased speed and capacity because the rate at which material could be put through the hatch did not increase, and it took longer to load the larger holds. This offset the faster speed of the ships.

The only significant improvement in cargo handling has been made in the loading of bulk cargo such as ore and oil. Conveyors and other automatic equipment can load specially-designed ships with these commodities at rates as high as 2000 to 3000 tons per hour. Contrast this with the rate of loading general cargo, which is approximately 10 to 20 tons per hour per hatch or a maximum of 50 to 100 tons per hour if five hatches are loaded simultaneously. Opportunities for the use of mechanical loading methods on the ordinary cargo ship, however, are limited by the fact that the ships are designed for flexibility; i.e. to accommodate a wide variety of commodities.

A ship earns no revenue while it is tied up in port and, in addition, the average cargo ship has a fixed port cost of $2000 to $3000 per day. Revenue comes from the charges on the transportation of goods by water, not from storage on shipboard at the dock. In wartime, the extremely heavy demands on shipping

and the easy target that a docked ship provides give additional reasons for reducing the turn around time.

There is considerable "know-how", of course, but little formulated information on the subject of cargo handling. Several of the components of the system have been subjected to systematic analysis by naval architects, terminal designers, material-handling specialists, economists, and others, but a systematic analysis has not been made of the system as a whole.

Realizing the need for a study of the subject, the Department of Engineering at the University of California, Los Angeles, in 1951, proposed a cargo-handling research project that received the financial support of the Office of Naval Research and the Maritime Administration. This is the first of a series of technical reports on the project.

Since the subject of cargo handling is extremely complex and includes many variables, the first objective of the study was to order these complexities and find the relations between the variables; i.e., to formulate equations that state these relations. After these relations are known and understood, they can be used to solve many specific cargo-handling problems.

Part I of this report outlines the steps necessary to determine these relations: a study of the background of cargo handling, a definition of the system, a formal analysis of it, and observations of actual cargo-handling operations.

Part II shows how specific cargo-handling problems can be solved after the relations between the variables have been determined. It also describes the techniques used in obtaining data and the conceptual models that were developed to aid in the research.

A bibliography of cargo handling is included as well as a list of references to literature in such related fields as materials handling, motion study, statistics, operations analysis, network analysis, logistics, transportation, economics, and labor relations.

The next report will give in detail the results of extensive observations of actual cargo-handling operations during the summer of 1953.

PART I.

SECTION I. BACKGROUND

A brief outline of the history of cargo handling is included here as a necessary preliminary to the report itself. An understanding of this background makes it possible to view the present situation as a dynamic system, with aspects that are not always visible.

In discussing the changes that have taken place in cargo handling over the years, it is convenient to consider the major elements of the system separately, although these elements are interrelated and some developments have affected more than one component.

Facilities

There were very few piers or quays in existence before the Civil War. Much of the cargo handled in the United States at that time was transferred between ships and the shore with the aid of harbor lighters. Shortly after the Civil War, the Port of New York hired General George McClellan to lay out a pier system on the water front[4*]. He designed what is known as the "American Pier System", an arrangement that is now used in New York, Boston, Philadelphia, and San Francisco. In this arrangement piers are about 1000 ft. long and 100 to 200 ft. wide, with

*Superscript numbers refer to references listed at the end of this report.

slips approximately 250 ft. wide between the piers. Four 500-ft. vessels can tie up at each of these piers.

An alternative to the pier is the quay, which is parallel with the basin and has water only on one side. This arrangement has been developed in the ports of Long Beach, San Diego, New Orleans, Galveston, and elsewhere. On the quays, there are spur railroad tracks, transit sheds, and possibly warehouses. An advantage of the quay is the accessibility of the working area to rail and truck. However, this design requires a sizeable body of navigable water or a large area of marginal land that can be easily dredged.

Recently, there have been moves to combine some of the features of the pier and quay design into a new type of facility. Examples of this can be found in San Francisco where both the American President Lines and the Matson Lines are using facilities with the slip between the two conventional piers filled in. Railroad tracks and access roads lead into this additional area. The objective is to allow for a large number of freight cars or trucks to be held conveniently at the pier area and to give easier access to the entire length of the transit sheds.[8]

One other design that is being used more frequently in modern ports is the 500 ft. by 500 ft. square pier. A transit shed covers the entire pier area with the exception of an apron that varies in width from 20 to 35 ft. A pier of this type can handle ships on three sides. These piers usually have spur railroads and adequate access for trucks. Several new piers of this type have recently been completed in Boston.[11]

Before 1850, piers in this country were uncovered; if goods were left on the pier overnight, they were protected by tarpaulins. By 1865, a few skeleton sheds had been built and, by 1876, practically all the large piers on the North River in New York were covered. After World War I, several 2- and 3-story concrete sheds were built. In most cases the first story of these sheds was used for incoming cargo and the second was used for outgoing cargo. The third story was used as warehouse

space.[4]

The trend in the newest facilities is to return to the 1-story shed. These new sheds are high roof, clear span, steel arch construction. Many of them are about 200 ft. wide and more than 500 ft. long. This type of shed can be seen in Wilmington, N.C., Providence, R.I., and Long Beach, California.

The modern forklift truck, which was introduced about 1930, is now used universally in the United States for cargo handling in conjunction with another important piece of equipment, the pallet. The pallet is of permanent type and is fairly rugged. It is used over and over again for storing or for transferring loads from one point to another within the limits of a facility.

Other types of equipment used extensively include conveyors, grain trimmers, ore unloaders, etc. However, these are limited to the handling of bulk commodities such as coal, ore, grain, sugar, etc. Specialized machinery has also been developed for loading and unloading bananas.

The harbor lighter has been largely overlooked in the United States, but, in European ports, it is the principal means of transferring cargo between the warehouse or transit shed, and ship or river barge.[4] It has found some use, however, in American ports where direct access to the pier cannot be made easily by railroads or motor trucks.

The wharf crane is another piece of equipment that has never found much acceptance in American ports although these cranes are common in European facilities, and have been in use in certain German ports since the 14th century.[4] In place of gantry cranes many American ports use the house fall from the steel girder structure above the transit shed roofs. This is less expensive than using the shoreside crane, but the house fall lacks the flexibility and maneuverability of the crane.[13]

To summarize: the port facilities in the United States have changed considerably in the last century. Terminals have been modified to accommodate the truck, the larger vessel, and

mechanized material-handling equipment.

Sea Transport

While there are many factors that determine the design of a merchant vessel, of prime interest in this study are the cargo-carrying characteristics of ships. These include the ship's carrying capacity, the equipment for handling, the design of the holds, the shape and size of the hatches, and the various safety devices. The speed of the vessel, though it does not directly affect the cargo-carrying characteristics, determines the frequency of the sailings and the overall rate at which cargoes are transported so it too is important in this study.

There has been a substantial increase in vessel size during the last century. In the 1860's, merchant ships had a capacity of about 1000 net registered tons (NRT). (The net registered tonnage of a ship is defined as the cargo carrying volume of the ship in cubic feet divided by 100.). This tonnage increased slowly until the passage of the Maritime Act of 1936. Then C-2's and C-3's were built with capacities between 9000 and 12,000 NRT. The Liberty and Victory ships, which were turned out in great quantities during World War II, had a capacity of approximately 10,500 NRT. The new Mariner class vessels have continued the trend of increasing capacity and can carry 12,900 NRT.[3]

There have been few changes in the gear used in general or package cargo handling operations. The winches and booms on a present day cargo ship differ little from those found on vessels built 50 years ago. However, electric winches have replaced some steam winches, winch controls have been grouped so that one man can operate two winches, and jumbo booms have been installed.

Before World War I, the cargo booms were usually supported on a boom table 8 feet above the main deck. During World War II, the boom was pivoted at the deck level. This trend has now been reversed, and the cargo boom is again being pivoted above the deck level.

Among the new kinds of ship's gear recently introduced are the Farrell and the Calmar gears.[19] The salient feature of this type of gear is that it allows the load to move in more than one plane, thus increasing the area on the apron and in the square of the hatch that can be serviced by the hook without topping the booms.

The contours of the holds are determined by the hydrodynamic requirements of the hull and the location of the engine room. The majority of the general cargo vessels have their machinery amidships. This means that the aft holds are broken up by the shaft alley and therefore require more careful stowage.

Hatch size has increased somewhat over the years and the number of hatches has gone up as the vessels have grown larger. Side ports that allow the direct loading by fork truck or trailer have replaced hatches on some vessels operating on the Great Lakes, but there is no trend toward the adoption of side ports for ocean-going vessels.

Even though hatches have increased in size, it is still necessary to stow the cargo in the wings of the hold. This laborious operation requires many man hours. Farrell Coordinated Rolling-Wing Decks have been proposed to eliminate the movement of the individual units of cargo to the wings: the rolling decks are loaded while they are directly below the hatch opening and are then rolled into the wing recesses. The remaining space directly under the hatch opening can then be loaded.[12] A prototype of the rolling wing decks has been installed by the Army Transportation Corps in two vessels.

The speed of merchant vessels has increased significantly since the introduction of the steamship. The maximum speed of the average steam ship of the 1860's was about 6 or 7 knots. The power plants in these ships were reciprocating steam engines. By 1936, the maximum speeds of ships with reciprocating engines had increased to 11 to 14 knots. The C-2's and C-3's were built after that time and their steam turbine or diesel engine power plants produce maximum speeds of 15-1/2 to 17

knots. The Liberty ship of World War II is powered by a reciprocating steam engine and its maximum speed is 11 knots. The faster Victory ship uses a geared turbine engine of the type used in the C-3, and has a maximum speed of 17 knots. The new Mariner class vessels have a maximum speed of over 20 knots.[3]

More drastic changes have been made in the design of ships that are used for bulk cargoes like the ore boats of the Great Lakes and the very large intercoastal oil tankers. Radical designs for general cargo ships have been proposed and a few prototypes, e.g., the Seatrain and Car Port, have been built.

Inland Transport

Railroads handle from 50 to 75% of the cargo going through the average port and almost 100% of the cargo through some ports, such as Norfolk, Va., and Port Arthur, Texas.[5] This requires a large amount of space in the port area for switching and marshalling yards. In most cases, the cars are loaded or unloaded adjacent to inside or outside storage areas. Rarely is the cargo transferred directly between ships and freight cars.[4]

Since the general size and shape of railroad cars has changed very little over the years, the method of freight handling has remained fairly constant. One exception to this was brought about by the introduction of the forklift, which can enter a railroad car and remove a palletized load. However, the variations in freight car dimensions and door widths have restricted its use.

The use of the river barge as a means of transferring cargo between inland areas and a port facility has increased steadily. However, the greatest proportion of this traffic has always been in bulk commodities such as coal, oil, cement, etc., and since the river barge is restricted to navigable waters, only a limited number of ports can utilize this connection.[3]

Supplementing the railroads and barges in the 19th Century

were horsedrawn drays. The ports built during that period were designed to accommodate these vehicles and dray-ways were incorporated into the transit sheds. The early motor trucks were about the same size and could use the dray-ways with no trouble. Today, however, the trucks in common use are large diesel tractors pulling one or more 10-ton trailers. All of the new transit sheds are, of course, equipped with large platforms to facilitate the loading and unloading of the modern vehicles but except for the assistance of the forklift, trucks are loaded and unloaded today by the same procedures that were used with horse-drawn drays.

Commodity

Changes in types of commodities passing through American ports have had considerable effect on the cargo handling operations. The most significant change is the increase in the amount of finished manufactures exported. This category increased from about 25% of the total exports in 1900 to more than 50% in 1951.[7,10.] The greater the percentage of finished materials, the greater the percentage of packaged cargo. This has resulted in the development of unit loads and a decrease in the overall density of the cargo in the hold.

The unit load is a group of commodities that remain in a container or on a pallet during shipment and is of a size and weight that can be handled as a unit by the equipment involved. Containers and pallets are noted here because with the unitization of loads they become a part of a commodity. The pallets may be permanent (returnable) or expendable. Although there are many sizes of pallets they do not vary greatly from 4 ft. by 3 ft. by 6 in. The containers that are used vary a great deal from one situation to another. A number of companies have developed general containers that have capacities between 4000 and 12,000 lbs. Larger containers are used in special trades such as the barge shipment of loaded 19-ton trailer vans by the Alaska Freight Lines[6] and the shipment of loaded freight

cars in the Atlantic and Gulf coastwise trades by Seatrain Lines, Inc.

The increase in the amount of packaged cargo with the subsequent decrease in the density of the shipments has resulted in vessels leaving port full but not down. A discussion of this problem can be found in section IV. The development of new packaging materials and new types of packages has helped reduce breakage to a certain extent. Cargo containers in addition to their usefulness as unit loads, have been used to reduce pilferage.

Control

The control of the cargo handling system is a combination of management, labor and government. The management and labor groups involved include the shipping firms, the stevedoring companies, the land carriers, the longshoremen's unions, the marine unions, the land-carrier unions, and the various management and port associations. The longshoremen, the shipping and stevedoring firms, and the management associations are most directly concerned with control. The limits of control may in many cases be prescribed by the government.

The conditions under which labor works are the results of arbitration and agreement between the unions and the management. The first longshoremen's union of a permanent nature was organized in Boston in 1847. During the next 50 years, other unions were organized at various ports, and by the turn of the century some of the unions had been formed on an interport basis.[1] In 1909, the International Longshoreman's Association (ILA) was founded. This union is now the dominant one on the Atlantic and Gulf coasts. The International Longshoreman's and Warehouseman's Union (ILWU), formed in 1938, represents the majority of longshoremen on the West coast.

The two unions differ considerably in their contractual relations with management. For example, the ILA contracts call

for no skill-differential pay, straight-time pay between 8 A.M. and 5 P.M., an average gang size of about 21 men, and the hiring of labor on a casual basis. The ILWU contracts on the other hand call for skill-differential pay for certain jobs, time and one-half for all hours in excess of 6 between 8 A.M. and 5 P.M., an average gang size of about 16 men, and the use of a hiring hall for obtaining labor.

Labor also serves as a transporting agent and as a source of energy for the system and, consequently, is in the position of being an important part of the facility as well as a part of control. However, its role as a transporting agent is continually being reduced by the increased use of mechanical equipment.

The shipping companies operate the vessels and in some cases manage the terminals. In all cases, they are important elements of control and their policies have a direct influence on cargo-handling operations. For example, they decide on the nature of the cargo and its origin, destination, and time schedules: these three are the dominant variables in programming problems. Since the shipping in this country is highly competitive, the leaders seldom act in concert and, thus, there is considerable variation in their control policies.[14]

The contract stevedores work with the shipping companies and the longshoremen. They usually provide the cargo-handling equipment (other than the ship's gear) and supervise the operation. Their control is at the working level and variations may be as great as the individual differences of the men involved. The increased use of mechanical equipment, by requiring the stevedore to increase his capital investment, has reduced the number of stevedoring companies.

All these groups have associations, with objectives ranging from professional fellowship to contract negotiation for regional areas, and they vary from those exerting mild influence to those that are direct agents of control.

Government through its many channels, establishes limits

on the range of the control. The limitations come from laws such as the Merchant Marine Acts of 1920, 1928, and 1936, which were aimed at developing an American merchant fleet for use in foreign trade and as a military auxiliary in case of national emergency. The result of the 1920 act was the establishment of American shipping services in the more important trade routes. The Merchant Marine Act of 1928 set up ocean-mail contracts as an aid to shipping firms in overcoming the differential in operating costs between American and foreign ships. This act also increased and liberalized the Construction Loan Fund. The Merchant Marine Act of 1936, which is still in effect, aims at economic parity for American ship operators. This is accomplished by two types of subsidies, the construction and operating differential subsidies.[3] Government also, through labor and business legislation, exercises control over wages, hours, safety, and rates.

SECTION II. THE PROBLEM

The foregoing background information indicates some of the complexities of the cargo handling system and serves as an introduction to the problem itself.

The objectives in undertaking this study were twofold: (1) To determine the time, space, energy, and cost relationships for the loading and unloading of ships; and (2) to propose changes in packaging, mechanisms, and procedures to minimize the costs, time, energy, and space required. The wording of these objectives was intentionally broad since it was suspected that the transportation system would include many complex interrelationships. Such proved to be the case.

On the basis of interviews with military and civilian shipping leaders and observations on military and civilian piers, it was decided to limit the scope of the study, for the time being at least, to the basic system shown in Figure 1.

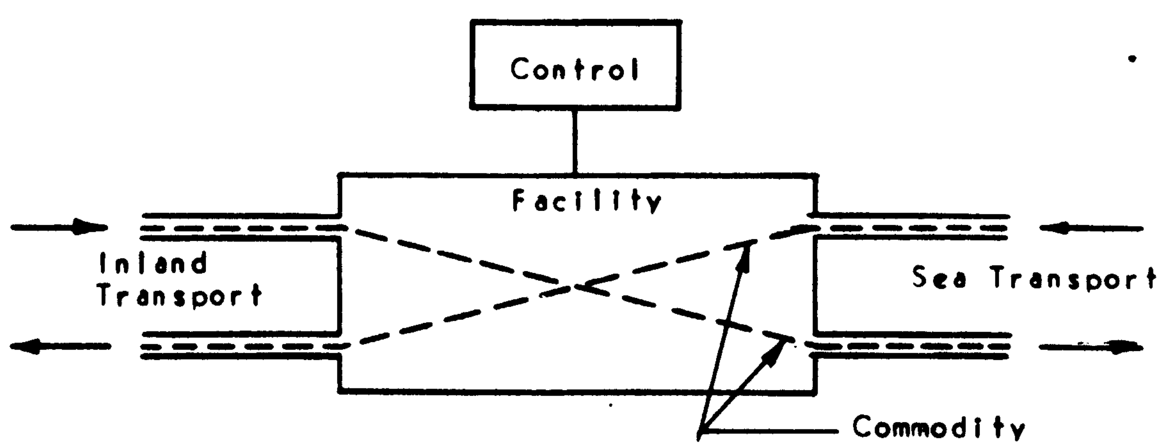


FIGURE 1

The cargo-handling system is defined here as consisting of five major elements: the facility (i.e. the physical equipment,

structures, and sources of energy), the transportation routes that are its inland connections, its sea connections, the commodities that flow through it, and the control of the system--a combination of management, labor, and government.

Since this system is based on a single facility and therefore does not take into account the interdependence that exists between facilities, the system shown in Figure I may be too specific and, possibly, at the same time, too general for adequate study. Therefore, it is anticipated that, as research progresses, there will be revisions and further analysis of the basic system.

An analysis of the cargo-handling system as defined above is a complex and formidable procedure. For one thing, the interrelations that exist within the system present a major difficulty. An immediate answer to a specific problem would affect the future solution of many others. Determining the present optimum size of the hatch opening, for instance, would affect all future attempts to design larger cargo containers.

Thus, it is apparent that, to avoid such premature solutions of specific problems, it is first necessary to find the relations existing between the system variables. This knowledge will make it possible to predict the effects of any change in one part on the rest of the system and at the same time, it will be possible to decide which specific problems to attack first.

The standards of measurement adopted for measuring the dependency between these variables were <u>time</u> and <u>cost</u>. In any realistic transportation problem, there is always some combination of both that must be taken into account.

Therefore, the first objective in this study is to <u>formulate equations that state the relations between significant components of the cargo handling system in terms of time and cost</u>.

After these relationships are known and understood, it will be possible to predict the effect of changes on the system and to design optimum systems.

Fortunately, it is not necessary to formulate equations that take into account all variables: a knowledge of only the more significant elements is all that is required to realize reasonable predictability. Of course, the equations can be made more accurate by including more variables since ". . . the behavior of the actual system is the limit of the behavior of the ideal system (I_n) as the idealization is extended,

$$I_n \longrightarrow \text{Behavior of Actual System}$$
$$\text{as } n \longrightarrow \infty$$

where n represents the number of the idealizations, each progressively including the more variables. . . . (or at least more accurately describing their effect)."[2]

The first step in determining the relations between the components is to make a formal description of the system and to develop a working model of it.

SECTION III. A FORMAL ANALYSIS OF CARGO HANDLING

The following formal analysis of the cargo-handling system at first glance may seem elementary and over-simplified, but it is a necessary first step toward the primary objective of this study, to devise equations that state the relations between the significant components of the system.

To begin with, the transfer of cargo between a land carrier and the hold of a ship occurs at what may be called a junction in the transportation network. The cargo handling that takes place at this junction is defined as the transfer of physical objects between a land carrier and a ship by men with machines. The major elements in this system are shown in Figure 1. They are defined as follows:

FACILITY (F) consists of the structures, materials-handling equipment, and sources of energy at the terminal, and the physical features of the port. Structures include the man-made improvements like roads, rails, and outside storage. Materials handling equipment includes the harbor lighters and barge cranes. The energy sources available for the transportation of cargo are electrical, mechanical, and thermal as well as manpower. Physical features are the contours, tides, and weather. In general, these are natural, but they may be altered, i.e. by dredging or the construction of breakwaters.

SEA TRANSPORT (S) is the vessel that carries the cargo to another facility. The cargo-handling gear on the ship is included.

INLAND TRANSPORT (L) is the carrier that connects the facility to the inland area. This may be truck, train, airplane, or river barge. All the material-handling equipment attached to the carrier is included.

COMMODITY (C) is the item that is shipped, including the package

or crate. Dunnage, however, is considered to be a separate commodity.

CONTROL (M) is the communication of information that regulates the movement of the commodity through the facility. The record system is included in control and both labor and management are involved.

The commodity follows a unique path through the facility, determined by all of the elements defined above. If F, S, L, C, and M are considered causes, the path is the effect. The effect may be observed in the field and subsequently used to induce information about the causes. Thus, the dependent element is defined as follows:

PROCESS (P) is the space-time coordinates of the path taken by the commodity or the transporting agent.

Symbolically, the principal elements of the system may be represented as vectors with components as follows:

Facility:	$F = (f_1, f_2, \ldots . f_n)$
Sea Transport:	$S = (s_1, s_2, \ldots . s_n)$
Inland Transport:	$L = (l_1, l_2, \ldots . l_n)$
Commodity:	$C = (c_1, c_2, \ldots . c_n)$
Control:	$M = (m_1, m_2, \ldots . m_n)$
Process:	$P = (p_1, p_2, \ldots . p_n)$

where f_1, $f_2, \ldots . f_n$, for example, are numbers that describe the facility; f_1 may be the number of berths, f_2 the net usable area, etc. There will be n different components ordered according to their importance. Thus, the first of the F components may be used to describe the facility within some predetermined level of completeness. This is also true for the components of S, L, C, M, P, although the number of components may be different for each element.

It is postulated that these six elements completely define the cargo-handling system and are necessary and sufficient for

the transfer of cargo between a land carrier and the hold of a ship at this junction in the transportation network. Recall that PROCESS is the dependent element, and as such is a function of the independent elements F, S, L, C, and M. One of the components of PROCESS is time, a basic measure.

When a transporting agent is used to move the commodity, the operation is cyclic. The transporting agent, which may be a forklift, hook, longshoreman, etc., moves with the commodity from one point to another and then returns to the starting point to repeat the operation. By this definition, pipelines, chutes, and certain types of conveyors such as roller conveyors are not considered to be transporting agents. Belt conveyors, however, are cyclic and consequently are considered transporting agents. A schematic diagram of a specific cyclic process is shown in Figure 2.

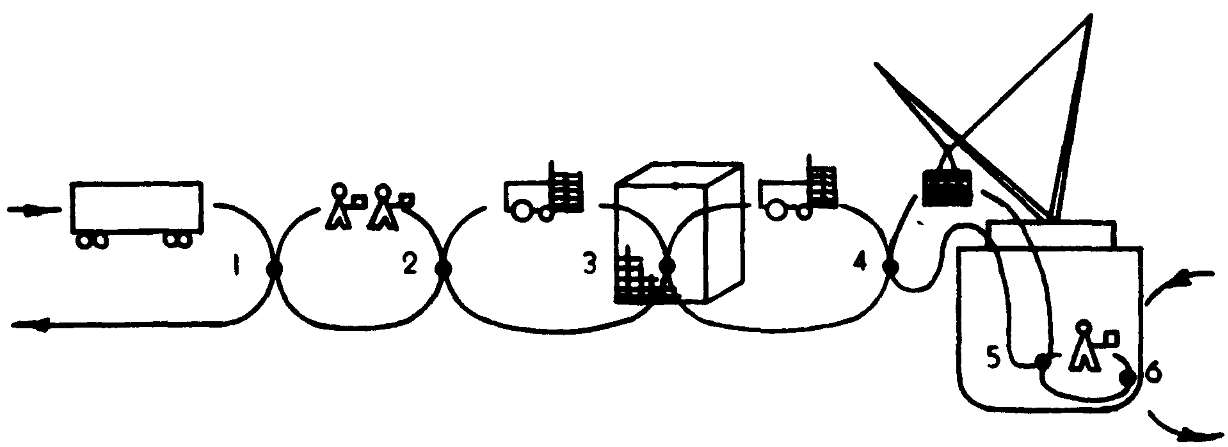


FIGURE 2

A commodity, cases of canned peaches, arrives at point I by rail. These cases are unloaded by four men, one case at a time, to a pallet at 2. The transporting agent here is a person. There are four transporting agents completing the same cycle. The unit of commodity is one case of canned peaches, described by the dimensions, weight. strength of

carton, etc.

A forklift picks up 36 cases stacked on the pallet in a definite pattern and moves the pallet to the transit shed. The unit of commodity is now a pallet of 36 cases. In addition to the dimensions, weight, etc., the maximum allowable acceleration is an important characteristic since the cases should not topple from the forklift en route. Point 3 is the location of the stack in the transit shed. The strength of the carton may become an important component of commodity during storage because it influences the height to which the commodity may be stacked.

After a period of time in storage, the commodity, still a pallet load of peaches, is moved by forklift to the apron, 4. The pallet is hoisted over the side of the ship and into the hold, 5. In the hold the pallet is unloaded by the hold men, one case at a time, and stowed in the wings, 6.

The loading of peaches can be shown schematically in the generalized cycle diagram shown below, in Figure 3.

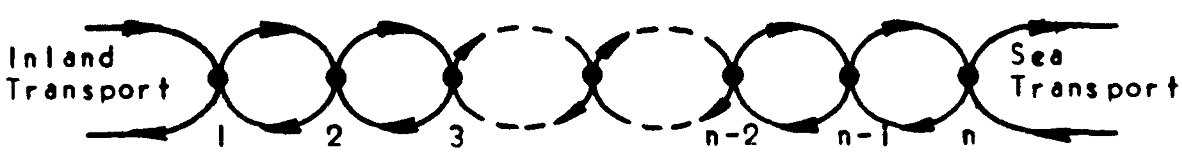


FIGURE 3

Each link in the chain represents the space time trajectory of the transporting agent. The trajectory of the commodity is, of course, unidirectional and is represented by either the upper or lower segment of the link. At the nodes (i.e. points) 1,2,3...n, the commodity is transferred from one transporting agent to another. It is not necessary that the transfer take place at a point in space or time: i.e., the commodity may be moved some distance by a gravity chute or roller conveyor or it may be put in storage for a period

of time. See Figures 4 and 5.

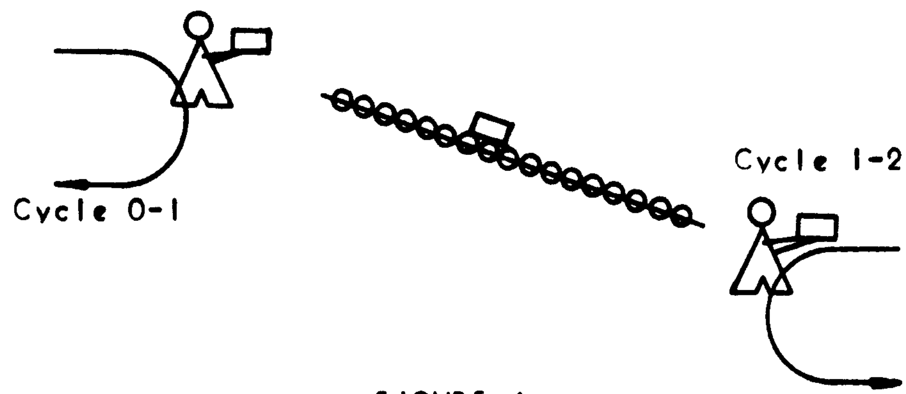


FIGURE 4

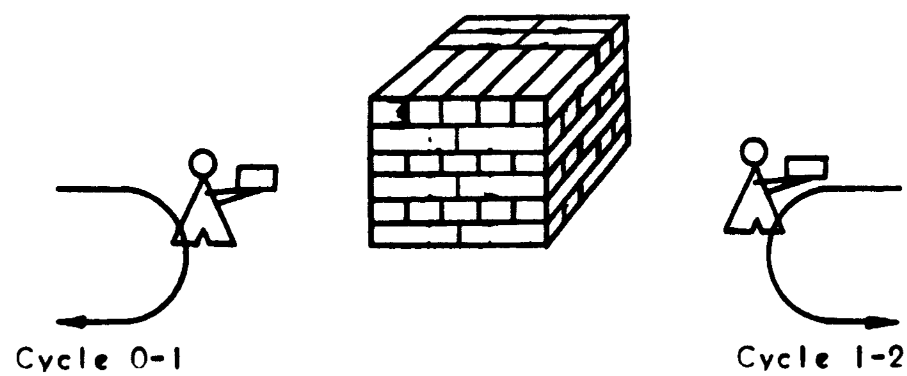


FIGURE 5

It is also possible for the unit of commodity to be changed at these nodes; e.g. a case of peaches to a pallet load. Between two consecutive nodes, the commodity is moved by a transporting agent. The unit of the commodity does not change and there are no storage states. If the commodity stops, it is in a delay state. The inland and sea transport are shown as open cycles in Figure 3. However, the inland transport cycle is closed if the inland origin or destination of the commodity is considered, and the sea transport cycle is closed if other facilities are included in the system. In the first case, the box car, barge, or truck is the transporting agent, and, in the second case, the vessel is the transporting agent.

The receiving dock, transit shed, apron, and hold of

the ship are nodes, and an analysis of the material flow through the facility may be based on a material balance at each node. The amount of commodity in storage at a node at the end of a specified interval of time is equal to the amount in storage at the start of the interval, plus that delivered by the transporting agent of the preceding cycle, less the amount of commodity taken away by the following cycle. The inputs and outputs can be expressed as Fourier series and their sum is an analytical expression of the quantity in storage. This is developed further in section IX.

The amount of the commodity stored at any node can obviously never be less than zero or greater than the maximum capacity of the node. Storage areas are limited by the allowable floor loads, ceiling heights, net usable areas, etc. Instability of the stack, allowable compressive stress, etc., also limit capacity as does the release and pick-up characteristics of the transporting agent. For example, the hook with married fall rigging can only pick up a load from a limited area on the apron. Thus, it is not possible to build a stockpile on the apron that can be hoisted over the side of the ship without additional handling. The vertical travel of the platform of a fork truck is another limitation imposed by the transporting agent.

Consequently, the maximum and minimum allowable storage at the nodes are bounds on the cargo-handling process. No goods can be taken from a node if the quantity in storage is zero and no goods can be deposited if the maximum amount is already in storage. Thus,there is the feedback situation illustrated in Figure 6. In this example, cargo is picked up at node 1 by a transporting agent and transferred along path 1-2 to node 2, where it is set down. The transporting agent returns along path 2-1 to node 1, where it can proceed to pick up another load. If there is no cargo present at transfer node 1, this information is given to the returning transporting agents. They are delayed until some minimum quantity

of cargo has been deposited at node I. The path for this information is represented by b. On the other hand, should node 2 be loaded to capacity, that information is given to the approaching transporting agents via path c. This delays them until there is room to deposit the load at node 2. Path a carries the overloading message of node I to the preceding cycle. Path d carries the message of the quantity at node 2 to the following cycle. A more detailed analysis is given in section X, which describes an electric analog of the cyclic process.

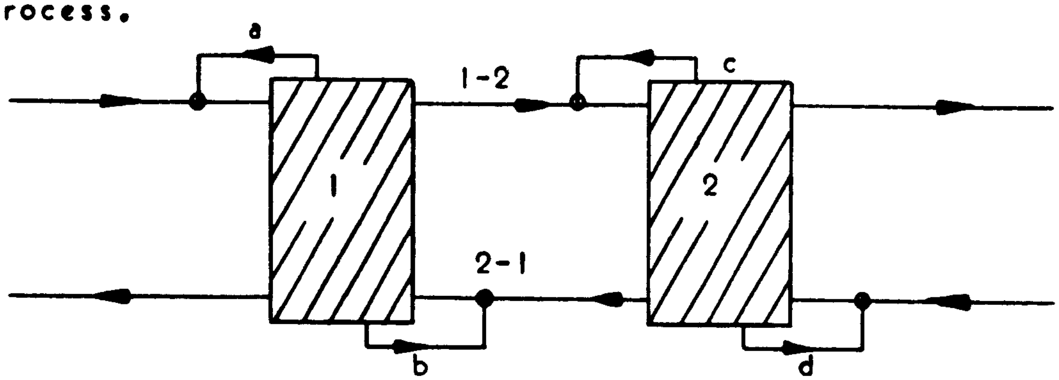


FIGURE 6

A material balance at each node may be supplemented by an analysis of material flow between nodes. The commodity is picked up by the transporting agent, carried to the next node, and released. The transporting agent then returns empty to the starting point. At any point in the cycle, there may occur a delay. The delay can originate outside or inside the cycle. If the delay is caused by the storage condition at either node, it is called an induced delay. All others are called internal delays. The total time that it takes to complete one round trip of the transporting agent can be broken down into element times as shown in Figure 7. The operation time, T_o is the sum of the element times of the particular cycle. Internal delays are included because there are always certain delays associated with the operation. Induced delays, on the other hand, are not charged to the cycle. When the transporting agent makes several round trips in succession, the element times are the

average values.

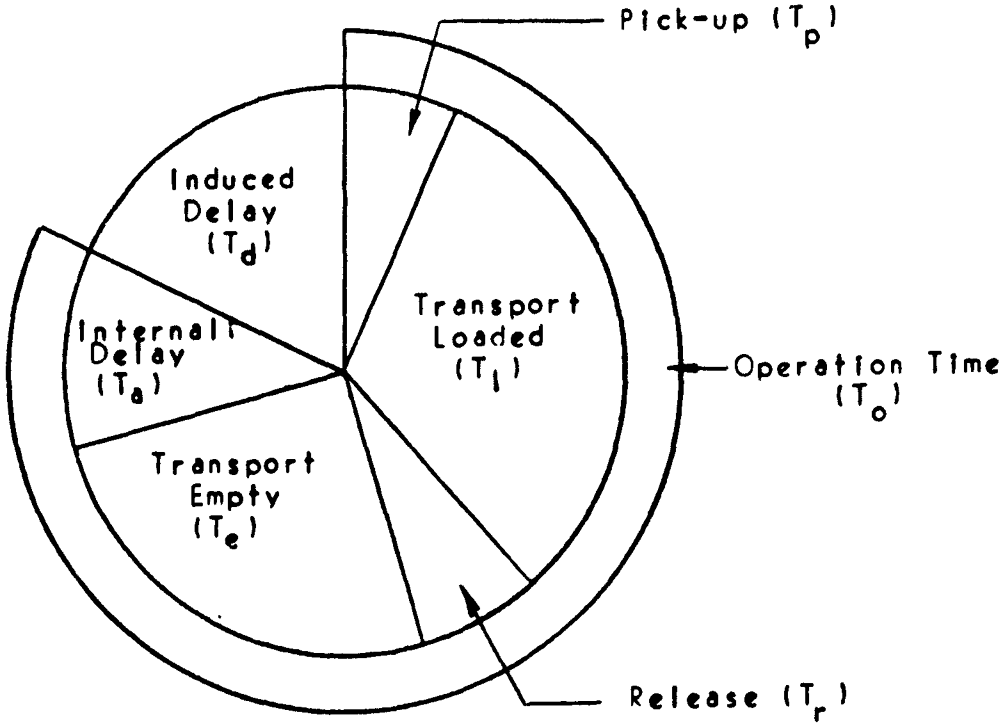


FIGURE 7

The rate at which the commodity is moved from one node to the next is defined as the weight of the commodity carried by the transporting agents per trip divided by the average time required to make the trip. If during an interval of time, the net change in the amount of storage at a node is zero, the average rates of flow in the preceding and succeeding cycles are equal. However, the operating rate of each cycle may be different. It is defined as the weight transported divided by the average operating time T_o. The operating rate is determined by the characteristics of the particular cycle only and is not influenced by the restrictions imposed by the adjacent cycles. The cycle with the lowest operating rate controls the rate at which commodity is moved from one point of storage to another. For example, in Figure 2 the rates between nodes 1, 2, and 3 are equal and the rates between 3, 4, 5 and 6 are equal. Furthermore, there is one cycle in each series of cycles that controls the remainder. All other cycles must have induced delay.

The element cycle times can be used as the dependent variable for one set of relations between the major elements. If the element times can be determined as a function of a reasonable number of parameters, the total time required can be calculated for a specific cycle. With additional information about the storage conditions at the nodes, the time required for an entire cargo handling operation can be predicted.

To sum up: it has been possible to devise equations for the flow of material through a particular ideal cargo-handling system. These equations can be used for the prediction of the time required to load or unload cargo or for the development of optimum methods and designs. They could be extended to the prediction of energy requirements and dollar costs by a transformation of the coordinates.

SECTION IV. METHODS OF PROBLEM SOLUTION

The scientific method of problem solution can be roughly divided into four major steps: (1) idealization of the system, (2) data gathering, (3) data processing, and (4) comparison of the idealization with the results. This is the approach that has been used here to solve the cargo-handling problem outlined in section II. A brief description of the methods used in these four steps is given below as an introduction to the following sections, where solutions for sample cargo-handling problems are worked out.

Before starting any investigation, it is necessary to formulate a model system to use as the basis for the inquiry. In this project, the model or idealization is based on the flow of materials. It could be based on the flow of energy or the flow of information. If all three models were formulated, the result would be a set of networks that could be superimposed upon each other. As stated earlier, these idealizations will approach the behavior of the actual system as they progressively include more variables and describe them more accurately.

In data gathering, the primary sources of data are the existing drawings, files, and reports kept by the various management, labor, and government groups that are concerned with cargo handling but the information derived from these sources consists mainly of cost data and past performances. Other sources are very limited and, in most cases, the data available do not coincide with the data required. It was necessary, therefore, to obtain field data from observation of cargo-handling operations.

There are a number of techniques that could be used to obtain actual time data of cargo-handling operations but the

work-sampling technique discussed in section VII has been found in most situations to be less time-consuming, cheaper, and more acceptable to employees than the conventional stop-watch time study. The forms used for both of these procedures are shown in the appendix along with a sample facility survey sheet and a process chart. The next report on this project will give a detailed description of these observational techniques.

The data obtained in these ways are then processed in accordance with the hypotheses to be tested, i.e., to check the idealization against the observed results. Processing consists of sorting and classification, computing statistics, multiple correlations, and fitting curves analytically and graphically. An example of the processing of cost data is shown in section VI. The processing of actual element time data and the development of postulates explaining the results will also be covered in the next report.

PART II.

The following sections show how sample problems can be solved by using the techniques outlined in part I. Also included is a description of the procedures developed to obtain field data and a description of an electrical analog that was designed to serve as a conceptual model of the system.

SECTION V. MAXIMIZING REVENUE TONS

The following is an illustration of a programming problem where a known relationship between certain variables is utilized. The specific problem is to maximize the revenue tons carried by a cargo vessel. Before proceeding to the actual solution of the problem, it may be helpful to define and illustrate some of the terms and concepts that are used.

Cargo vessels may be considered to have two measures of capacity. There is the volume capacity, measured by the number of cubic feet of goods that can be stowed, and the weight capacity measured in tons of stowed goods. The weight capacity is determined by the safe depth to which a vessel may be loaded.

The commodities to be transported by general cargo vessels have a rather wide variation in density, or its reciprocal, the more commonly used stowage factor. Since some commodities are very dense, while others are less so, a problem exists in programming the cargo to be carried so that the vessel will be full and down at the time of sailing: i.e., all the cargo space filled and the ship down to its draft limit marks. If the entire cargo were cotton, the vessel would be full but not down. If, on the other hand, the entire cargo were lead ingots, the ship would be down but not full. There is a combination of cotton and lead, however, that will both fill the ship and bring it down to its draft limit marks.

There are a number of ways of selecting cargos that meet this requirement. For purposes of military logistics, where cost is of less consequence than the scarcity of ships, the maximum quantity must be delivered by each ship in the least amount of time. However, for commercial purposes, the total revenue to be derived is the primary consideration. The unit

used is the revenue ton, which is defined as the actual weight of the commodity in long tons or one fortieth of the volume in cubic feet, whichever is higher. Generally, revenue tons for commodities with a stowage factor greater than forty are computed on the basis of the volume, while for commodities with stowage factors less than forty, the revenue tons are computed from the weight. An additional factor is the shipping charge in dollars per revenue ton prevailing for each class of commodity. Hence, when a steamship company has some leeway in the selection of cargo, certain selections will yield higher values of revenue tons than others, and some will yield higher total revenue than others.

Any combination that results in a vessel being full and down is an "efficient" solution. The programming problem of maximization of revenue tons can be solved readily as follows:

Let f_i = stowage factor of a commodity i that is available for loading and that is greater than 40 ft^3/ton.

Thus $f_i > 40$ and $i = 1, 2, 3, \ldots n$

Let g_j = stowage factor of a commodity j that is available for loading and that is less than 40 ft^3/ton.

Thus $g_j < 40$ and $j = 1, 2, 3, \ldots n$

Then for all f_i's, revenue tons are computed by volume.

Let x_i = revenue tons of commodity i

$$x_i = \frac{v_i}{40} \quad \text{where } v \text{ is the volume occupied in } ft^3 \qquad (1)$$

For all g_j's, revenue tons are computed by weight.

Let y_j = revenue tons of commodities j

$$y_j = d_j \quad \text{where } d \text{ is the long tons of saltwater displaced when the commodity is stowed.} \qquad (2)$$

The total revenue tons for a given ship will be

$$R = \sum_{1}^{n} x_i + \sum_{1}^{m} y_j \tag{3}$$

where values of $x_i = 0$ and $y_i = 0$ are not excluded. Negative values of x_i and y_j are excluded for physical reasons. A properly loaded cargo vessel will be one for which R is a maximum. The limiting factors are of course the maximum values of any x_i and y_j, the volume of the cargo spaces, and the net displacement of the vessel available for cargo.

These limitations may be expressed as follows:

$$\sum_{1}^{n} v_i + \sum_{1}^{m} v_j \leq V \quad \text{The net cargo capacity by volume} \tag{4}$$

$$\sum_{1}^{n} d_i + \sum_{1}^{m} d_j \leq D \quad \text{The net cargo capacity by weight} \tag{5}$$

The optimum of this system is obviously reached when both equalities are obtained, i.e.:

$$\sum v_i + \sum v_j = V \tag{6}$$

$$\sum d_i + \sum d_j = D \tag{7}$$

where

$$v_i = 40\, x_i \tag{1}$$

$$v_j = g_j\, y_j \tag{8}$$

$$d_i = 40\, x_i / f_i \tag{9}$$

and

$$d_j = y_j \tag{2}$$

therefore the equations

$$V = \sum_{i}^{n} 40x_i + \sum_{i}^{m} g_j y_j \tag{10}$$

$$D = \sum_{i}^{n} 40x_i + \sum_{i}^{m} y_j \tag{11}$$

represent a ship loaded full and down, that is, all cargo space is filled and the ship is down to the draft limit marks.

The number of revenue tons loaded will be given by the sum

$$R = \sum_{i}^{n} x_i + \sum_{j}^{m} y_j \tag{3}$$

with x_i and y_j subject to equations (10) and (11).

For a ship loaded with a single commodity, equations (10) and (11) are independent and R will be determined solely by either the volume capacity of the vessel or its displacement capacity as the stowage factor is either greater or less than 40 cu. ft. per ton.

A vessel may be loaded with two commodities in any combination. If both commodities have a stowage factor greater than 40, or if both are less than 40, then the optimum load would be a homogeneous cargo of one or the other, as for a single commodity. If, however, one is f_i and the other is g_j, a programming is possible to determine the optimum amounts of each commodity to be carried. Equations (10) and (11) now read:

$$40x_i + g_j y_j = V \tag{12}$$

$$40x_i/f_i + y_j = D \tag{13}$$

These equations are not independent and a solution for x_i and y_j is possible that will result in the vessel being

full and down.

Eliminating x_i we have

$$y_j = \frac{f_i D - V}{f_i - g_j} \tag{14}$$

$$x_i = \frac{f_i}{40}\left[\frac{V - g_j D}{f_i - g_j}\right] \tag{15}$$

As an example of equations (14) and (15), consider the problem of loading a vessel, which, after allowance for stores, fuel, etc., has a gross tonnage of 7,000 and a deadweight capacity of 10,000 tons. The vessel is to be loaded with cotton and steel with stowage factors of 100 and 10 respectively.

Substitution in equations (14) and (15) yields:

x_i = 16,666 revenue tons of cotton

y_j = 3,333 revenue tons of steel

so that the total revenue tons carried,

R = 20,000 tons

This quantity is considerably greater than either the nominal displacement or nominal volumetric capacity of the vessel by a substantial amount. It is apparent that there is an important economic reason for a ship owner to attempt to maximize revenue tons in this way.

The next question that may be raised is: what should the values of f_i and g_j be to make R a maximum?

Substituting equation (14) and (15) into (3)

$$R = \frac{f}{40}\left(\frac{V - gD}{f - g}\right) + \left(\frac{fD - V}{f - g}\right) \tag{16}$$

(disregarding the subscripts)

(Note that in equation (16) $f \neq g$ except for a one-commodity system in which R is determined by either weight or volume, whichever is larger.)

Differentiating (16) with respect to f and g with V and D as parameters gives

$$\frac{\partial R}{\partial R} = \frac{1}{f - g}\left[\frac{V - gD}{40} - \frac{f}{40}\left(\frac{V - gD}{f-g}\right) + D - \frac{fD-V}{f-g}\right] = 0 \qquad (17)$$

$$\frac{\partial R}{\partial R} = \frac{1}{f - g}\left[\frac{-fg}{40} + \frac{f}{40}\left(\frac{V - gD}{f-g}\right) + \frac{fD-V}{f-g}\right] = 0 \qquad (18)$$

One possible solution is

$$\frac{1}{f - g} = 0 \qquad (19)$$

This solution represents maximum revenue tons since it represents a ship loaded with two hypothetical materials, one which has volume but no weight and the other which has weight but no volume. The alternative solution represented by the quantity in the brackets can be shown to be $f - g \longrightarrow 0$. Therefore, both f and g will approach the same value and the situation will be similar to that of a single commodity. In this case, the revenue tons will be equal to either the first or second term of equation (3). Thus, the first solution, $\frac{1}{f - g} \longrightarrow 0$ represents the solution for maximizing a two-commodity system.

Now consider the general system consisting of commodities available for loading of $f_1, f_2, f_3 \ldots . f_n$, and $g_1, g_2, g_3 \ldots$ $\ldots g_n$. Since $f_i > 40 > g_j$, we may arrange the f_i's in descending order of magnitude while the g_j's may be ordered in increasing values.

$$f_1 > f_2 > f_3 \ldots\ldots > f_n$$

$$g_1 < g_2 < g_3 \ldots\ldots < g_m$$

Since a combination of f_1 and g_1 will give a greater value of revenue tons than any other combination, it follows that the general solution to equations (10), (11), and (3) will be obtained when the highest and lowest density materials available are loaded until one or the other ceases to be available. In this case, the remaining displacement and volumetric capacity, together with the remaining commodity selection, form a new programming problem whose solution is obtained in exactly the same manner.

The implications of this solution are that very high or very low density commodities might have a lower cost per revenue ton, since they yield a higher total revenue tonnage when they are shipped together. This problem, however, is further complicated by the fact that the cost per revenue ton for various commodities is dependent on many other factors that have not been considered here. Future study along this line will probably be fruitful and, of necessity, more complicated.

SECTION VI. ANALYSIS OF LOADING COSTS

There are many costs associated with the loading of a ship. The manner in which they are broken down varies with the different shipping companies. For the following analysis, the costs are divided into the same categories used at one of the installations under study. These costs are of two types: the fixed costs, which are not dependent on the tonnage being loaded, and the variable costs, which are dependent on the tonnage being loaded. They include:

<u>Fixed Costs</u>

Tug Service
Pilotage
Dockage
Ship Operating Expense
Office Expense

<u>Variable Costs</u>

Handling and Clerking
Dunnage and Shoring Material
Lashing Labor

The following is a discussion of the actual values of these costs and is representative for one port and for the loading of a Liberty type vessel.

<u>Tug service</u>: The total charge for tug service for a ship inbound and outbound is $100, providing there is no shifting from berth to berth.

<u>Pilotage</u>: The pilotage charge is $0.005 per gross registered ton inbound, and the same charge outbound. For Liberty type vessels, which have an average gross registered tonnage of around 7200, this charge is $72 total, inbound and outbound.

<u>Dockage</u>: This cost is computed as $12 for 1000-1500 net registered tons per 24 hours or fraction thereof, and $3 per

24 hours for each additional 500 net registered tons or fraction thereof. For simplicity, the turn around time of a ship will be reported in this analysis to the full day above any fraction of a day. Therefore, the dockage cost can be approximated as:

$$\text{dockage} = T\left[12 + 3\ \frac{N - 1500}{500}\right] \qquad (20)$$

where T = turn around time (in 24 hours)
N = net registered tonnage

Since the net registered tonnage of a Liberty is 4414, equation (20) reduces to:

$$\text{dockage} = 30\ T \qquad (21)$$

Ship Operating Expense: This is the expense that the ship incurs while in port, i.e., wages, food, fuel, etc. This cost is estimated to be $2200 per day for a Liberty type vessel. Thus, in equation form, the ship operating expense is:

$$\text{ship operating expense} = 2200\ T \qquad (22)$$

Office Expense: This cost can be charged as a fixed cost per long ton loaded. This assumes that office expense is independent of the turn around time. Therefore, the office expense can be expressed as:

$$\text{office expense} = L\left(\frac{E}{R}\right) \qquad (23)$$

where L = long tons
E = office expense per year
R = tonnage per year

Since the amount of tonnage per year (R) is confidential for the facility in question, this cost has not been included in the analysis. The only effect of this cost would be to

shift the resulting family of curves upward on the ordinate scale.

Handling and Clerking: Certain assumptions must be made in order to evaluate the handling costs. First of all, a uniform loading rate of 25 long tons per gang hour is used for all commodities and all working time. An 18 man gang with the required clerking aid is assumed, with a maximum of 5 gangs on any one ship. It is also assumed that the least costly arrangement of working time is chosen. This means that the amount of overtime is minimized. Analytically, the handling and clerking cost is expressed as:

$$\text{handling} = A_D C_D + A_O C_O \tag{24}$$

where A_D = number of "day time" gang shifts
A_O = number of overtime gang shifts
C_D = cost per "day time" gang shift (i.e., 6 hours straight time and 2 hours overtime)
C_O = cost per overtime gang shift (i.e., 8 hours overtime)

and
$$C_D < C_O \tag{25}$$

From the assumptions made above it is also seen that:

$$A_D \leq 5T \tag{26}$$

and
$$A_D + A_O = \frac{L}{25(8)} = \frac{L}{200} \tag{27}$$

Thus to obtain minimum cost in handling:

$$A_D = 5T \tag{28}$$

Substituting equations (27) and (28) into (24) and the resulting handling cost is also expressed as:

$$\text{handling} \;=\; 5TC_D + \left(\frac{L}{200} - 5T\right) C_O \qquad (29)$$

The following numerical example illustrates these equations.

Assume that a Liberty type vessel is to be loaded with 2000 long tons of average commodities. The total gang shifts required for this operation, as determined from equation (27), are:

$$A_D + A_O \;=\; \frac{2000}{200} \;=\; 10 \text{ total gang shifts} \qquad (30)$$

If the turn around time is one day, then the maximum number of "day time" shifts is determined from equation (28).

$$A_D \;=\; 5(1) \;=\; 5 \text{ "day time" gang shifts} \qquad (31)$$

and $$A_O \;=\; 10 - 5 = 5 \text{ overtime gang shifts} \qquad (32)$$

Assuming that the C_D = \$475 and C_O = \$600, substituting these values in equation (24) gives:

$$\text{handling} \;=\; \$5375 \qquad (33)$$

If, however, the vessel can remain in port for 2 days, then equation (30) still holds but the value of A_D changes.

$$A_D \;=\; 5\,(2) \;=\; 10 \text{ "day time" gang shifts} \qquad (34)$$

and $$A_O \;=\; 10 - 10 = 0 \text{ overtime gang shifts} \qquad (35)$$

The cost of handling now becomes:

$$\text{handling} \;=\; \$4750 \qquad (36)$$

Thus, the extra day in port has reduced the handling

costs but the other costs, such as ship operating expense, would have nullified this saving.

Dunnage and Storing Material: This cost is determined from data obtained at the facility. If a linear relation is assumed between these costs and the long tons, then, in the facility under study, the relationship has been found to be approximated by the following equation:

$$\text{dunnage} = 300 + 1.11\,(L) \tag{37}$$

Lashing Labor: This cost is primarily a function of the commodity and cargo plan as well as the tonnage loaded, but since it is quite variable and less significant than many of the other costs, it is omitted in this analysis.

The resulting total cost for loading a Liberty type vessel can then be expressed as:

$$\begin{aligned}\text{total cost} = {} & \text{tug service} + \text{pilotage} + \\ & \text{dockage} + \text{ship operating} \\ & \text{expense} + \text{handling and clerking} \\ & + \text{dunnage and storing material}\end{aligned} \tag{38}$$

Substituting the values discussed above, equation (38) now becomes:

$$\begin{aligned}\text{total cost} = {} & 100 + 72 + 30T + 2200T \\ & + (3L - 625T) + (300 + 1.11\,L)\end{aligned} \tag{39}$$

By dividing both sides of equation (39) by the long tons (L) being loaded the equation for cost per long ton is found to be:

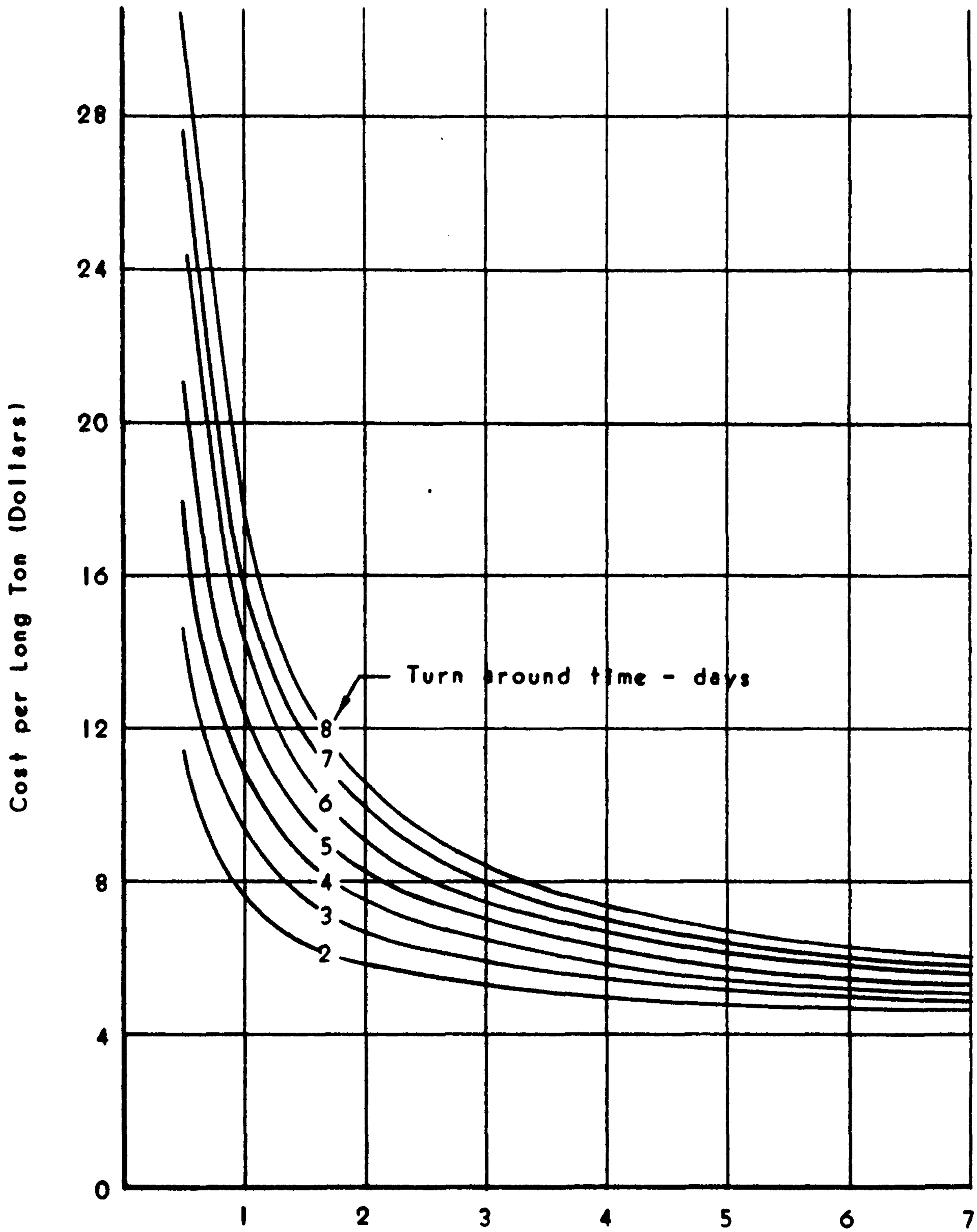
$$\begin{aligned}\frac{\text{cost}}{\text{long ton}} = {} & \frac{100}{L} + \frac{72}{L} + \frac{30T}{L} + \frac{2200T}{L} + \left[3 + \frac{625T}{L}\right] \\ & + \left[\frac{300}{L} + 1.11\right]\end{aligned} \tag{40}$$

Gathering terms reduces equation (40) to:

$$\frac{\text{cost}}{\text{long ton}} = \frac{472}{L}(1 + 3.4T) + 4.11 \qquad (41)$$

Equation (41) is plotted in Figure 8 with cost per long ton vs. the tonnage loaded, and turn around time (T) as the parameter of the family of curves. For the example being studied, these curves show that with a given tonnage the most economical time to load in is the shortest time. It also shows that, for a given turn around time, the optimum tonnage to load is the largest possible tonnage. This conclusion can be derived directly from equation (39), which shows that the only costs varying with turn around time are dockage, ship operating, and handling costs. Both dockage and ship operating costs are increasing straight line functions of time. Handling cost, on the other hand, is a decreasing step function of time as illustrated above in the discussion of handling costs because, for two-thirds of a day, the handling costs are charged with overtime penalty. However, the decrease in the handling cost with time is always smaller than the increase in ship operating and dockage costs. This situation exists for the assumptions and limitations made in this analysis, i.e., a specific longshore pay structure, a particular ship type, etc. It is obvious that the smaller the ship operating cost (and dockage cost), the smaller the saving becomes from using a minimum turn around time. Thus, a break-even point may exist for certain low-operating cost vessels.

In addition to the factors mentioned above, there are others that are important. They include the cost of the increased period of the commodity in transit and the loss of potential business while a ship is tied up in port. These may be appreciable and further stress the importance of shortening the turn around time by working overtime.



Cost per Long Ton (Dollars)
28
24
20
16
12
8
4
0
Turn around time - days
8
7
6
5
4
3
2
1
2
3
4
5
6
7
Tonnage Loaded (Thousands of Long Tons)

FIGURE 8

SECTION VII. WORK-SAMPLING TECHNIQUE FOR DETERMINING CYCLE ELEMENT TIMES

The work-sampling technique, originated by L.H.C. Tippet in 1935, suggests itself as a possible tool for obtaining actual time data of cargo loading and unloading operations. The use of work-sampling in this situation is a good deal more complicated than in the usual industrial situation. For one thing, the technique has usually been used for observations on individual workers; in the present study it is being used on gang or group activities. The resulting complications are, however, of a practical rather than a theoretical nature, and result mainly from the physical layout of the work place.

The work-sampling method itself is based on the random sampling theory employed in statistical quality control. The procedure is to select samples at random from the population, and, when a sufficient number of observations have been taken, a prediction is made for the population. The prediction is based upon the theory that the percentage of readings recording the activity in a certain state of operation is an estimate of the percentage of time spent in that operation.

Before proceeding to the actual design of the work sampling method, it is necessary to review and expand the model of the cargo-handling operation developed in section III. In that section, the cargo operations are recognized and defined as a series of adjoining cycles. Each of the cycles is broken down into six time elements:

T_p = picking up load

T_l = transport loaded

T_r = transport release

T_e = transport empty

T_a = internal delay

T_d = induced delay

From Figure 7, it is seen that the sum of these elements equals the total cycle time (T):

$$T = T_p + T_l + T_r + T_e + T_a + T_d \tag{42}$$

Also, from Figure 7, the cycle operating time (T_o) is defined as:

$$T_o = T_p + T_l + T_r + T_e + T_a \tag{43}$$

The element times can be used in determining the effect that changes in the components have on the system. These element times can also be used in determining the rate at which the commodity is moved between nodes. For example, the rate of movement of a commodity between nodes 1 and 2 (r_{1-2}) is defined as:

$$r_{1-2} = \left(\frac{nw}{T}\right)_{1-2} \tag{44}$$

where n = number of transporting agents

w = weight of commodity carried by a transporting agent during each cycle

If a series of cycles have no storage nodes, then the rates of commodity movement are interdependent and

$$r_{1-2} = r_{2-3} = r_{3-4} = \ldots = r \tag{45}$$

However, the operating rates (r_o) are different and

$$(r_o)_{1-2} = \left(\frac{nw}{T_o}\right)_{1-2} \tag{46}$$

The cycle with the slowest operating rate (min r_o) and, therefore, the one with longest operating time, is the controlling cycle in the series of cycles. This relationship can be expressed as:

$$r \leq \min r_o \tag{47}$$

Turning now to the work-sampling method of obtaining the element times the following definitions are required:

N_p = number of random observations of picking up load

N_l = number of random observations of transport loaded

N_r = number of observations of transport release

N_e = number of observations of transport empty

N_a = number of observations of internal delay

N_d = number of observations of induced delay

Similarly to equation (42), the total number of random observations (N) is

$$N = N_p + N_l + N_r + N_e + N_a + N_d \tag{48}$$

Also, the number of random observations of cycle operating time is defined as

$$N_o = N_p + N_l + N_r + N_e + N_a \tag{49}$$

By hypothesis from the statistical theory underlying work sampling,

$$\frac{N_\alpha}{N} = \frac{T_\alpha}{T} = \frac{p_\alpha}{100} \tag{50}$$

where N_α = number of random observations of element (i.e., pickup, transport loaded, release, etc.)

T_α = time required for element

p_α = the α time element's percentage of total cycle time

Before any actual observations can start, it is necessary to obtain descriptive data on the type of ships, facilities, commodities, schedules, etc. that affect the systems being studied. It is then possible to make random observations of the activities with the more important activities receiving proportionately more observations. Therefore, the first step in designing the sampling plan consists of an analysis of the operation to be studied.

The next step is to determine the number of samples to be taken. This number is a function of the risk, the maximum size of confidence, the length of the time interval, and the variance. If a binomially distributed population is assumed, the number of samples can be determined from the formula for the standard error of a binomial.

$$\sigma_p = \frac{p(1-p)}{p} \qquad (51)$$

where p = a time element's percentage of the total cycle time.

If a percent of accuracy (β) is required in the determination of p, and if a percent of confidence (γ) is also required, then the usual statistic follows:

$$\frac{\beta}{100} p = Z_\gamma \sigma_p \qquad (52)$$

Equations (51) and (52) can be combined to give

$$N = \left(\frac{Z_\gamma}{\frac{\beta}{100}}\right)^2 \left(\frac{1-p}{p}\right) \qquad (53)$$

Equation (53) is plotted in Figure 9 with β and γ as

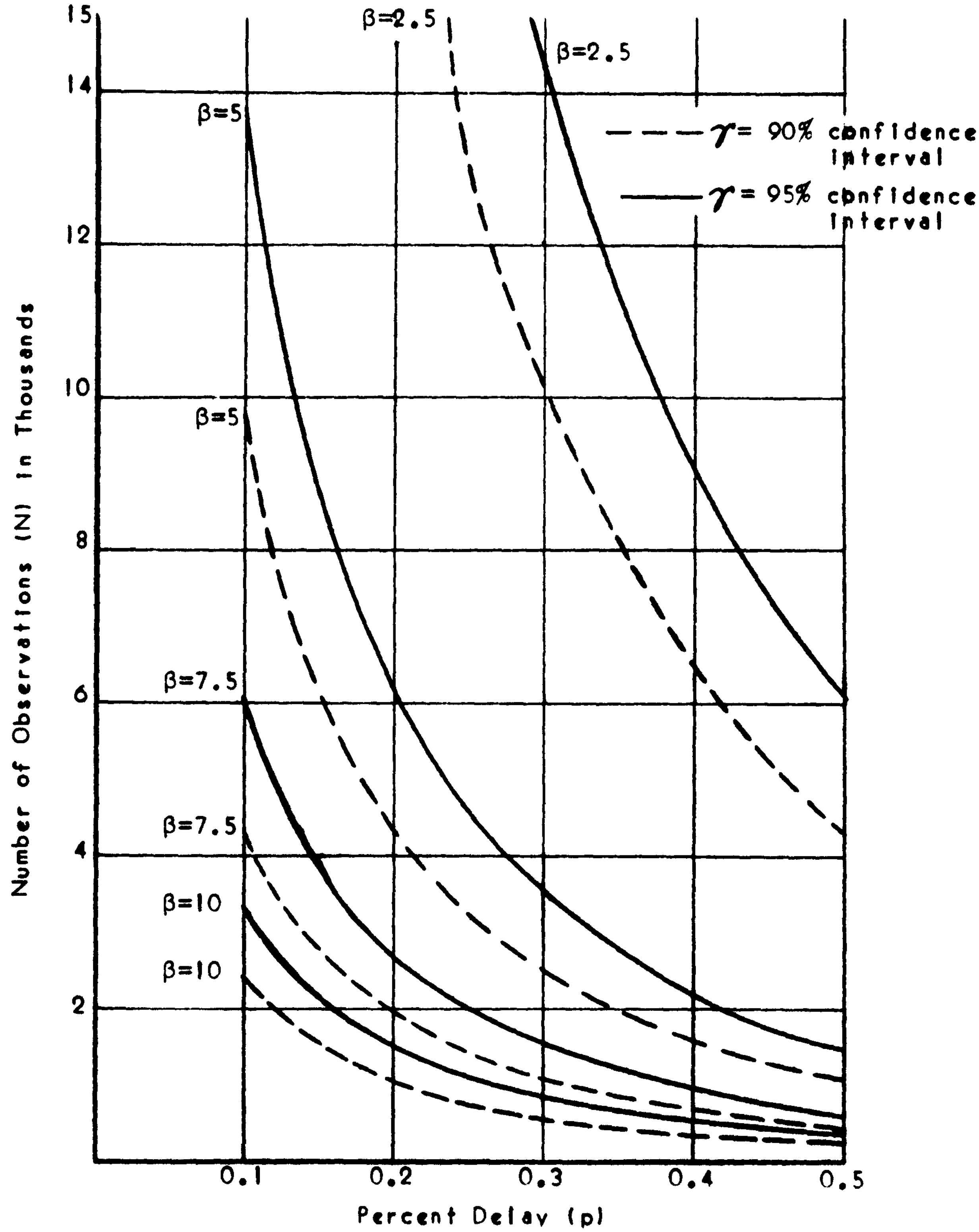

15
14
12
10
8
6
4
2
β=2.5
β=2.5
β=5
β=5
β=7.5
β=7.5
β=10
β=10
γ= 90% confidence interval
γ= 95% confidence interval
0.1
0.2
0.3
0.4
0.5
Percent Delay (p)
Number of Observations (N) in Thousands

FIGURE 9

parameters. The resulting relationship between p and N is hyperbolic and N decreases greatly with increases in p (i.e., increases in the length of the element time interval).

The important effect of this can be illustrated by an example. Assume a maximum allowable variance of ± 5% in the calculated p, and a confidence interval of 95%. If the value of p = 0.1, then 13,800 observations are required. However, if p = 0.5 then only 1500 readings are required. Thus, in a sampling plan with several p's, it is necessary to balance the reliability requirements and the practical number of observations that can be made. Since N is theoretically based on the smallest estimated p, it is sometimes necessary to combine some of the smaller elements or compromise on the reliability of prediction of the less important elements.

After the number of samples has been determined, the next step is the actual observation. Training procedure has been developed so that all observers will define the time elements in the same manner. The work sampling observation sheets I and II, as illustrated in the appendix, have also been developed as an aid in standardizing the procedure.

SECTION VIII. OPTIMUM WEIGHT TRANSPORT PROBLEM

The following is also an illustration of the way in which a relationship between variables can be utilized to find an optimum solution of a problem.

Suppose that a forklift is used to move cargo from one point on the pier to another as shown in Figure 10.

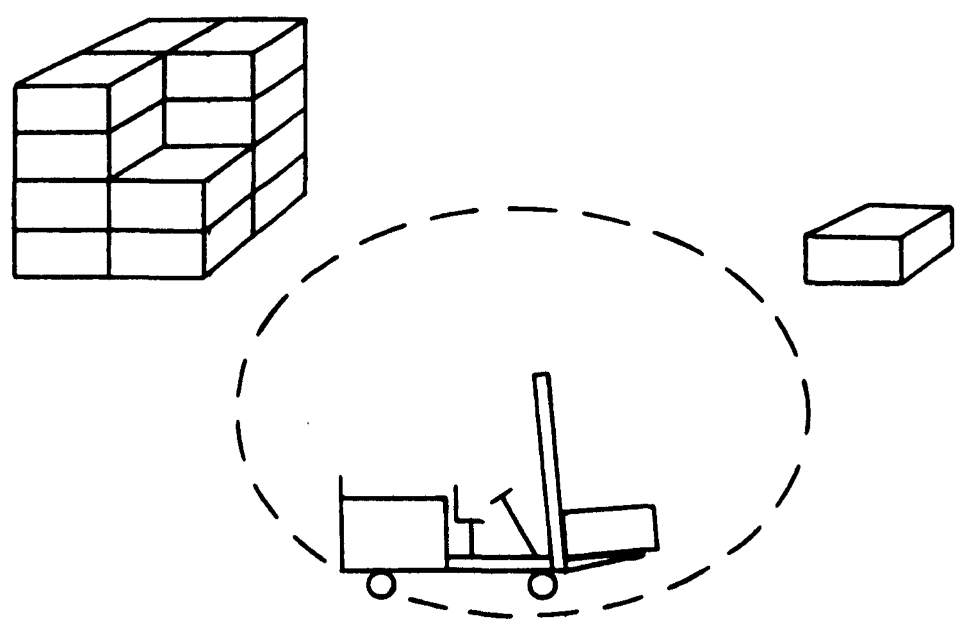


FIGURE 10

The time required for each round trip is the total of the time required to pick up the load, transport it from one place to the other, set down the load, and return to the starting point. The time required for certain of the steps, e.g., the return trip, will not depend upon the size of the load. The time required for the other steps, however, may depend upon the size of the load. If it takes longer to make the round trip as the load carried per trip gets heavier, there may be some optimum load that allows a

higher rate in tons moved per hour than lighter loads carried faster or heavier loads carried slower.

It seems reasonable to postulate that the time required for a round trip is some function of the load

$$t = f(w) \tag{54}$$

where t = round trip time

w = weight carried per trip

In many cases, the function could be expanded into a power series,

$$t = a_0 + a_1 w + a_2 w^2 + a_3 w^3 \ldots + a_i w^i \ldots + a_n w^n \tag{55}$$

where a_i = constant for $i = 0, 1, 2 \ldots n$

Consider the situation that can be described by the first three terms. (Often the higher power terms can be omitted without seriously reducing the value of the solution.)

$$t = a_0 + a_1 w + a_2 w^2 \tag{56}$$

Equation (56) can be made dimensionless by letting

$$t' = \frac{t}{a_1 w} \quad \text{, time number and} \tag{57}$$

$$w' = \frac{a_1 w}{a_0} \quad \text{, weight number} \tag{58}$$

Note that t' and w' are dimensionless numbers.

Equation (56) becomes

$$t' = \frac{1}{w'} + 1 + \frac{a_0 a_2}{a_1^2} w' \tag{59}$$

Equation (56) is represented in Figure 11 as a family of curves with a_0a_2/a_1^2 as the parameter. Note that there is a minimum number t' for each value of a_0a_2/a_1^2.

To find the expression for the curve drawn through these minimum points, the standard method of calculus is used.

$$\frac{dt'}{dw'} = -\frac{1}{(w')^2} + \frac{a_0a_2}{a_1^2} = 0 \qquad (60)$$

$$(w')_{opt} = \frac{a_1}{\sqrt{a_0a_2}} \qquad (61)$$

Substitute equation (61) into equation (59) and eliminate the parameter a_0a_2/a_1^2.

$$(t')_{min} = 1 + \frac{2}{(w')_{opt}} \qquad (62)$$

Equation (62) is represented by Figure 12. This shows the relation between minimum time number and optimum weight number for the condition postulated in equation (56).

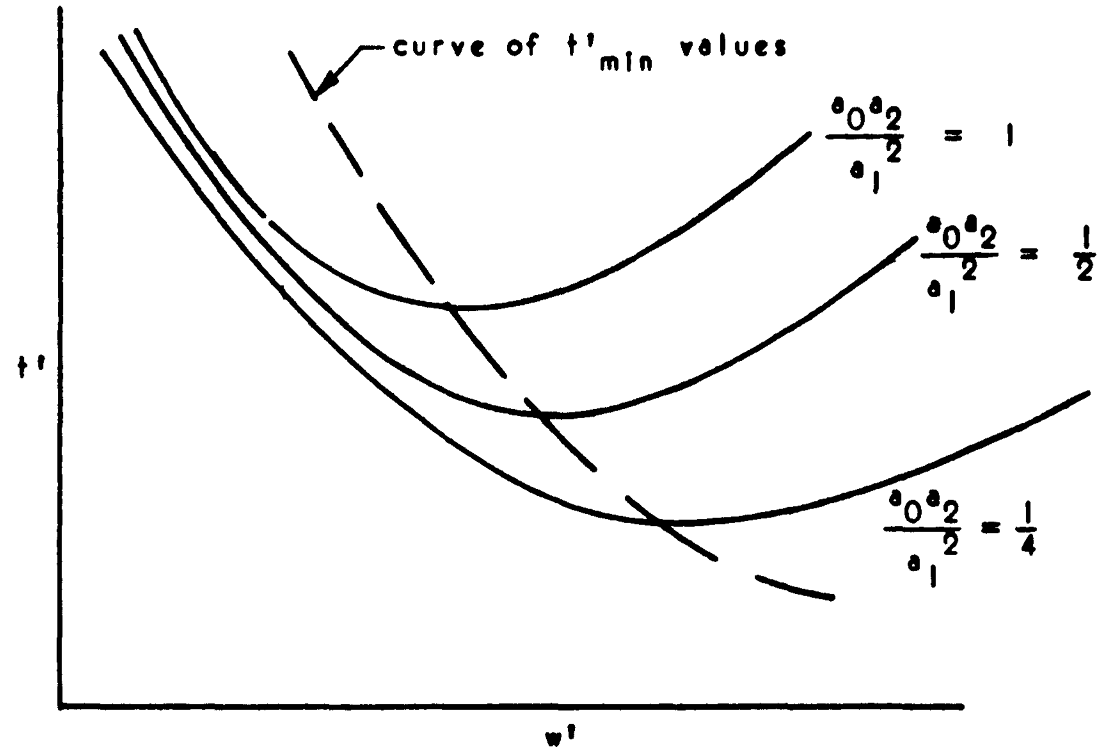


FIGURE 11

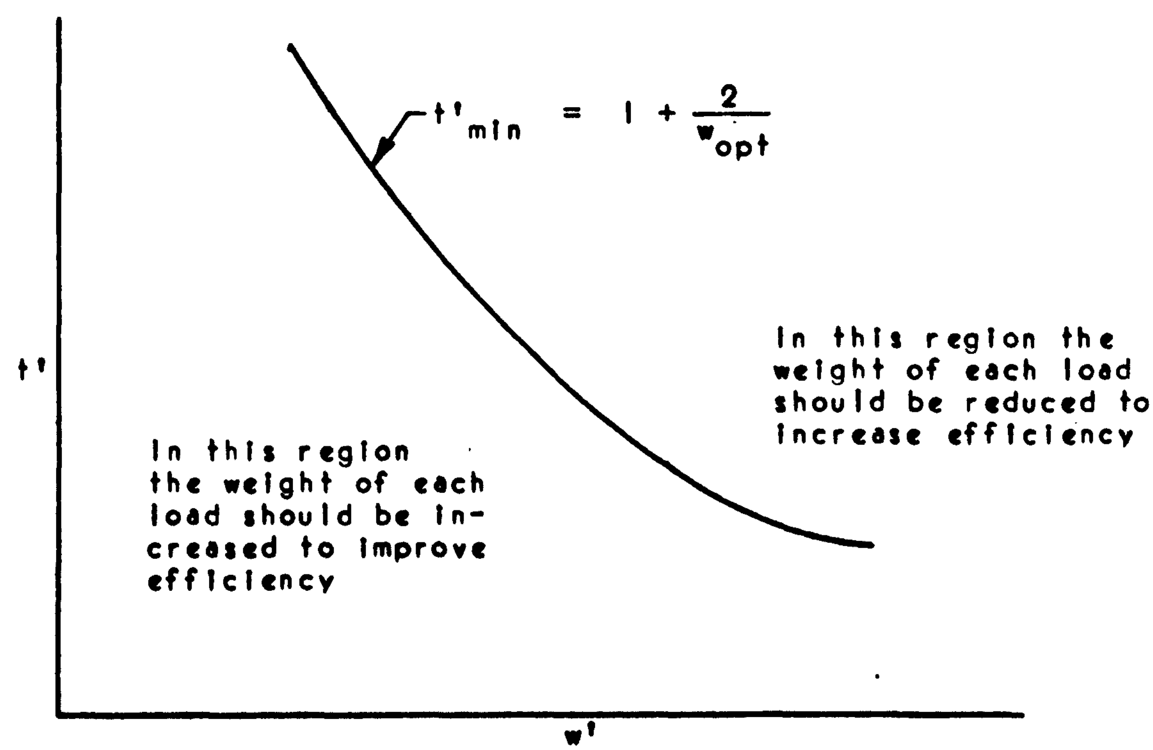


FIGURE 12

SECTION IX. AN ANALYSIS OF THE QUANTITY OF COMMODITY AT A STORAGE NODE

In section III it was pointed out that the quantity of commodity that is in storage at any node depends on the amount delivered and the amount taken away. The following is a more detailed treatment of the conditions that exist at the node.

Assume that the upper curve in Figure 13 is a graphical representation of an input and output to a node, and that the lower curve represents the resulting storage.

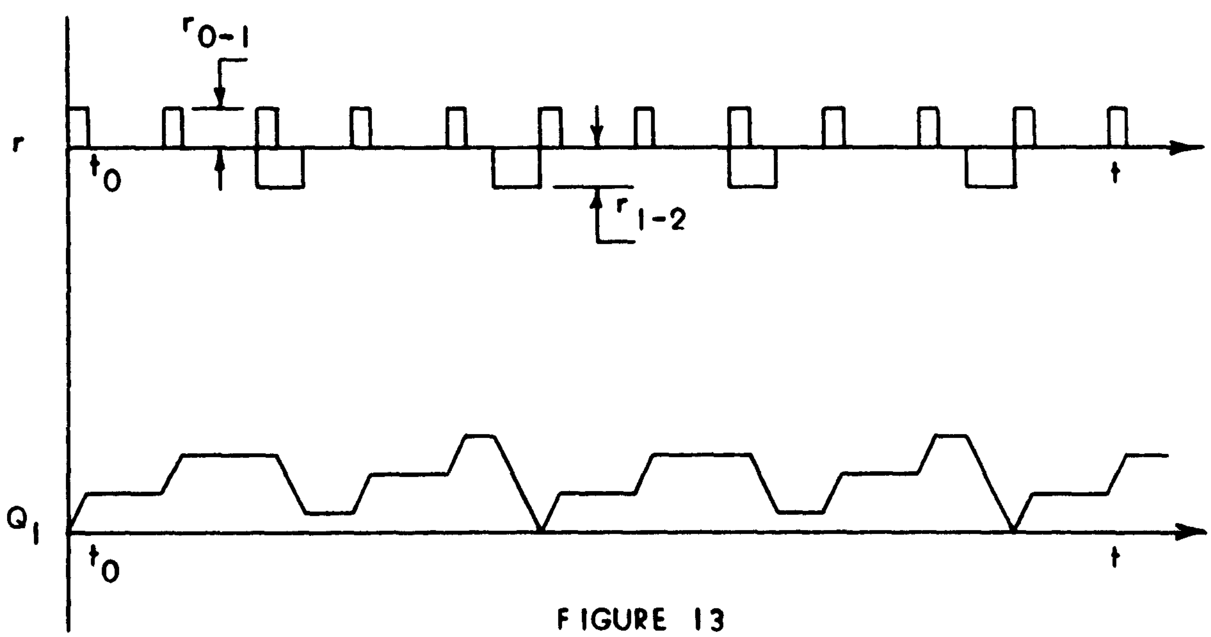


FIGURE 13

Both curves have time (t) as the abscissa. However, the ordinate of the upper curve is the rate of commodity movement in quantity per unit time (r), and the ordinate of the lower curve is the quantity of storage at node I (Q_1). In Figure 13, the positive portion of the upper curve is the input to node I. This can be thought of as representing delivery trucks that

arrive periodically at the node and are then unloaded at the rate r_{0-1}. The output rate from the node, or the negative portion of the upper curve, can represent ships that arrive periodically and are loaded at the rate r_{1-2}. The lower curve now represents the quantity that is in storage at node I at any time. This curve is obtained by integrating the upper curve from t_0 to t, plus the storage existing at t_0. In the example chosen, the storage existing at t_0 is assumed to be zero.

The foregoing graphical representation can be developed analytically by simply expressing the periodic input and output as Fourier series. For example, assume the input to a storage node I to be that shown in Figure 14.

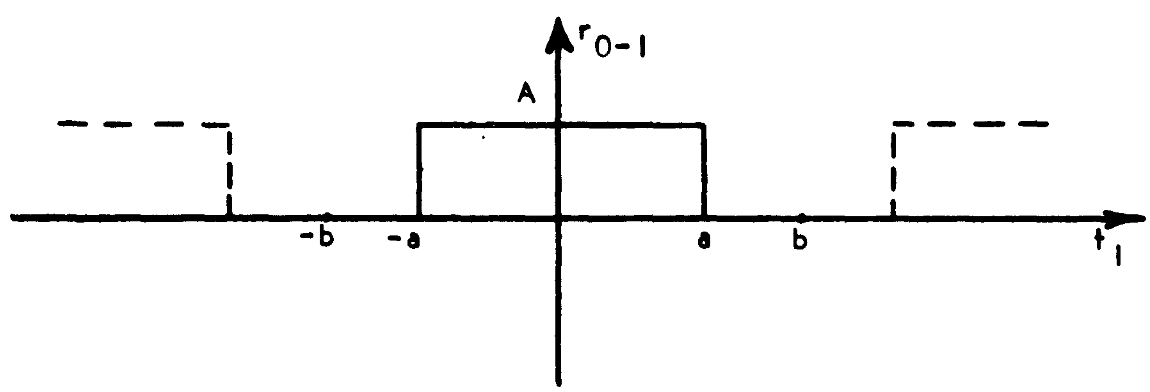


FIGURE 14

Similarly, assume the output from storage node I to be that shown in Figure 15.

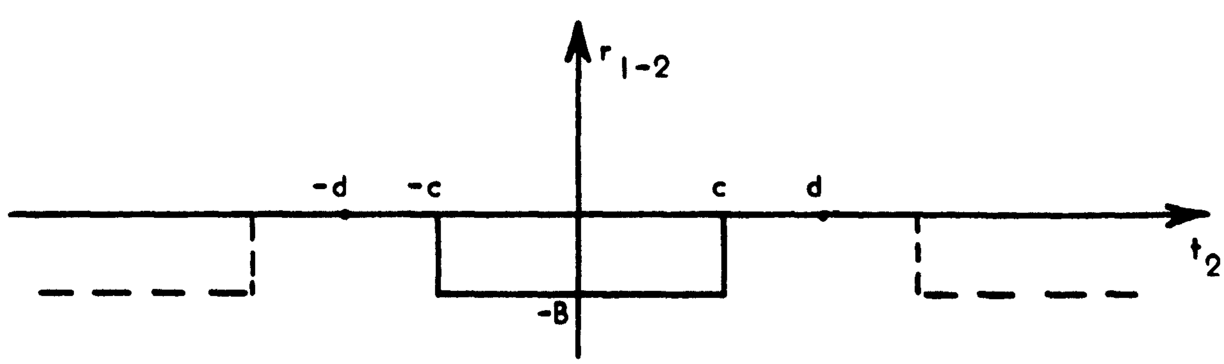


FIGURE 15

From Figure 14 it is seen that

$$r_{0-1} = f(t_1) = \begin{cases} 0(-b \leq t_1 < -a) \\ A(-a \leq t_1 < a) \\ 0(a \leq t_1 < b) \end{cases} \tag{63}$$

Since an even function is assumed, a cosine series can be used.

$$r_{0-1} = \frac{\alpha_0}{2} + \sum_{n=1}^{\infty} \alpha_K \cos \frac{K\pi}{b} t_1 \tag{64}$$

where α_0 and α_K are the Fourier coefficients. When these are determined in the usual way, the expression becomes

$$r_{0-1} = A\left[\frac{a}{b} + \frac{2}{\pi} \sum_{K=1}^{\infty} \frac{1}{K} \sin \frac{K\pi a}{b} \cos \frac{K\pi}{b} t_1\right] \tag{65}$$

Similarly from Figure 15 it is seen that

$$r_{1-2} = g(t_2) = \begin{cases} 0(-d \leq t_2 < -c) \\ -B(-c \leq t_2 < c) \\ 0(c \leq t_2 < d) \end{cases} \tag{66}$$

Again, an even function is assumed and a cosine series is used.

$$r_{1-2} = \frac{\alpha_0}{2} + \sum_{K=1}^{\infty} \alpha_K \cos \frac{K\pi}{d} t_2 \tag{67}$$

and

$$r_{1-2} = -B\left[\frac{c}{d} + \frac{2}{\pi} \sum_{K=1}^{\infty} \frac{1}{K} \sin \frac{K\pi c}{d} \cos \frac{K\pi}{d} t_2\right] \tag{68}$$

In the foregoing, it was assumed that the input and output are timed separately with times t_1 and t_2. If they are timed simultaneously, then $t_1 = t_2 = t$ and the total rate of storage at node 1 is

$$\frac{dQ_1}{dt} = r_{0-1} + r_{1-2} \tag{69}$$

Substituting equations (65) and (68) into (69) and the resulting rate of storage is

$$\frac{dQ_1}{dt} = \left(\frac{aA}{b} - \frac{cB}{d}\right) + \frac{2}{\pi}\left[\sum_{K=1}^{\infty} \frac{1}{K}\left(A \sin \frac{K\pi a}{b} \cos \frac{K\pi}{b} - B \sin \frac{K\pi c}{d} \cos \frac{K\pi}{d} t\right)\right] \tag{70}$$

The storage is the integral of the equation (70):

$$Q_1 = \left(\frac{aA}{b} - \frac{cB}{d}\right)t + \frac{2}{\pi}\left[\sum_{n=1}^{\infty} \frac{1}{K^2}\left(\frac{bA}{\pi} \sin \frac{K\pi a}{b} \sin \frac{K\pi}{b} t - \frac{dB}{\pi} \sin \frac{K\pi c}{d} \cos \frac{K\pi}{d} t\right)\right] \tag{71}$$

Since there is a maximum and a minimum storage, there can be no continuous increase of storage with time. Thus,

$$\frac{aA}{b} - \frac{cB}{d} = 0 \tag{72}$$

and the first term of equation (71) drops out. This relationship can then be utilized in solving for the constants in the remainder of the equation.

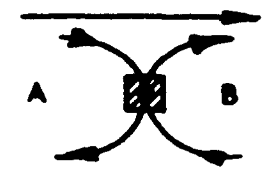
The foregoing analysis is also useful in solving for maximum storage areas required for specific cargo handling situations. The use of the Fourier series makes it possible to express any of the complex input and output rates in analytic form if they are periodic.

SECTION X. AN ELECTRICAL ANALOG OF THE CARGO-HANDLING OPERATION

The electrical analog shown in Figure 16 is useful as a conceptual aid in depicting the cyclic operation described in section III. The portion of operations illustrated includes parts of two connecting cycles, A and B, and the transfer node between them. The node is represented by the boxed-in area. To explain the operation of the circuit, a few of the many possible cases encountered in the transfer of cargo are discussed below.

The first case is a situation where the commodity is loaded by longshoremen directly on a tractor-trailer combination. The setting down of the commodity by the men occurs simultaneously with the pick-up by the tractor-trailer. To simulate this situation, switch 1 is in position m and switch 2 is in position p. Pulse generator 1 in cycle A and its counterpart in cycle B, pulse generator 2, deliver a number of pulses corresponding to the number of transporting agents in the particular cycle. Suppose a pulse, representing a longshoreman and his load, arrives from the previous node at storer 1. The longshoreman may be held up until a tractor-trailer combination arrives. Thus, the initial pulse remains in storer 1 and also energizes the lower path into and-gate 1. This condition remains until there is at least one pulse, representing the tractor-trailer, in storer 2. If there is a pulse in storer 2, a signal is sent over path a which energizes the upper line into and-gate 1. The operation of the and-gate is such that it allows a pulse to go through it only if both input lines are energized. Therefore, when there is a pulse in both storer 1 and storer 2, it allows a pulse to pass through and-gate 1 and to continue on through

Direction commodity moves



Schematic representation of the circuit below

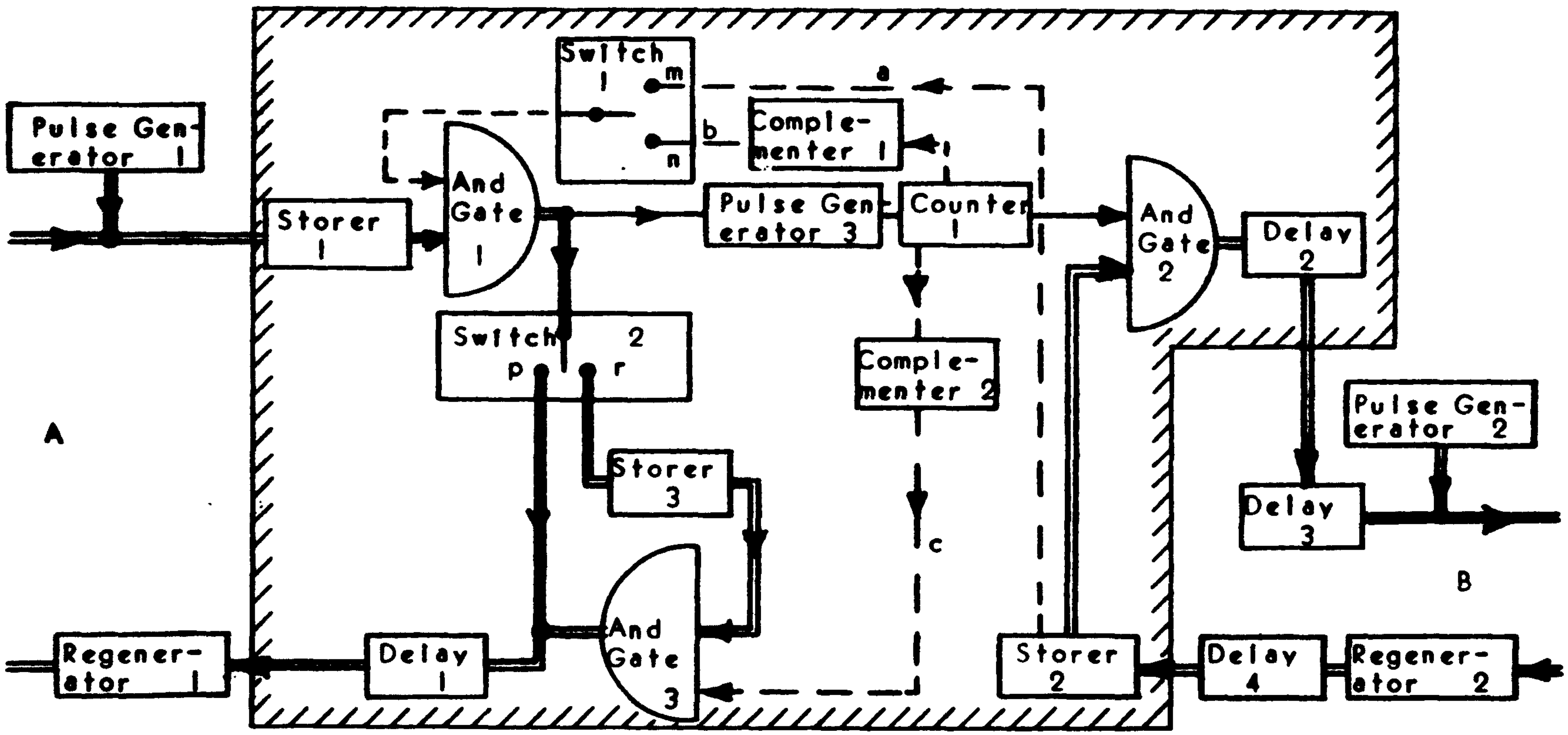


FIGURE 16

switch 2, delay 1, and regenerator 1. Delay 1 represents the unloading time and regenerator 1 restores the energy that has been dissipated in the circuit. Each impulse that passes through and-gate 1 acts to subtract one from the count on storer 1. However, for the sake of simplicity, this part of the circuit is not shown in Figure 16. In addition, the pulses from and-gate 1 also energize pulse generator 3, which in turn delivers to counter 1 the number of units of cargo for each pulse received. In this case, there is one unit of commodity carried by each transporting agent or pulse going through and-gate 1. Therefore, pulse generator 3 serves no purpose in this particular example. When the pulses stored in counter 1 reach a specified number, representing a fully-loaded tractor-trailer combination, it energizes and-gate 2, allowing the pulse in storer 2 to be released. This pulse passes on through delay 2, representing pick-up time, and delay 3, representing transit time. The pulse from and-gate 2 also acts on counter 1 and storer 2 in order to subtract one unit from each of them. Again, this subtracting circuit is not shown in Figure 16. Delays 2 and 3 can, of course, be combined, but they are separated here to clarify their function. The return path of the pulse in cycle B is through regenerator 2 and delay 4. Regenerator 2 restores the energy that is dissipated in the circuit, and delay 4 is set to correspond to the time of the return trip.

From this example, it is seen that the heavy lines can be thought of as representing the paths of the transporting agents, the light lines the transfer of the commodity from one cycle to the next, and the broken lines the paths of the various energizing or information signals.

The second case is the situation in which the arriving transporting agent deposits its load and returns immediately, thus leaving the commodity until it is picked up by the subsequent carrier. In this case, a forklift brings its cargo to a point on the pier where the cargo is set down. The fork-

lift then returns to the place where it can pick up another load to be delivered to the pier. Meanwhile, the commodity that is on the pier remains until the ship's hook can carry it away. The analogous electrical operation exists when switch I is in position n and switch 2 is in position p. Counter I now records the units of commodity that are on the pier where the hook may pick them up. In most operations, the hook can pick up from only one point on the pier, thus the maximum storage at counter I is one unit. If there are no units at counter I, then a signal is sent from complementer I over path b that energizes the upper line into and-gate I. This occurs because a complementer reverses whatever signal it receives. With the upper path into and-gate I energized a pulse in cycle A, which arrives at storer I, will continue on through and-gate I and will return to the previous node as in the first case. However, if counter I shows that there is a unit of commodity on the pier, then complementer I sends no signal over path b and in turn does not energize the upper line into and-gate I. Therefore, the arriving pulses will be held in storer I until counter I indicates zero. Counter I also controls and-gate 2. Thus, one unit on counter I energizes the upper line into and-gate 2, and zero units on counter I fail to energize it. A pulse in cycle B, representing the hook, arrives at storer 2 and remains there or passes on depending on whether the upper line into and-gate 2 is energized or not. The delays and regenerators in this example have the same functions as those described in the first case.

The third case is the situation that occurs when longshoremen are unloading a tractor and trailer combination. In the electrical analogy, switch I is in position n and switch 2 is in position r. The pulses in cycle A represent the tractor and trailer combinations and the pulses in cycle B represent the longshoremen. An impulse arriving at storer I will be held there unless counter I indicates zero units. This is a similar condition to the one described in the second case. If counter I has zero units, the impulse in storer I can

proceed into the path to storer 3 and into the path to pulse generator 3. Pulse generator 3 will then deliver to counter I the number of units of commodity corresponding to one arriving impulse. For example, a tractor and trailer combination are represented by one pulse in cycle A, but this same tractor-trailer may carry a dozen drums, which are then moved individually by the longshoremen. Therefore, for every pulse that enters pulse generator 3, twelve pulses will be delivered to counter I. And-gate 2 is controlled by counter I and the pulses that enter storer 2 can only proceed if there are one or more units of commodity indicated on counter I. When counter I indicates zero a signal is sent via path c from complementer 2, which energizes and-gate 3. This allows the pulse, which has been held at storer 3, to continue on its return trip. As noted in the other examples, there must also be a subtracting circuit to storer 3 in order to reduce the count on it after the pulses pass through and-gate 3. The delays and regenerators in this case again have the same functions as those described in the first example.

Aside from the three cargo-transfer operations described above, there are many other transfer operations that can be simulated by the same electrical analog. A series of these analogs could be set up to reproduce an entire loading operation from the storage in the transit shed to the storage in the ship, the storage points being counters that can stop the flow when a predetermined maximum is reached. Although the usefulness of this type of model is mainly conceptual, it is also possible to utilize it in determining loading times for commodities that have not been handled before.

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APPENDIX

FORMS AND THEIR UTILIZATION

Several of the following forms were developed especially for this project to record data obtained from field observations of actual cargo-handling operations; the others are commonly used in the work-sampling technique. The forms include the following:

1. Facility Questionnaire
2. Process Chart
3. Work Sampling Observation Sheet I
4. Work Sampling Observation Sheet II
5. Cycle Times Sheet
6. Tally Sheet
7. Time Study Sheet

1. Facility Questionnaire

The Facility Questionnaire (pages 66, 67 and 68) is used for obtaining information concerning the physical characteristics of the facility. The forms are self-explanatory and are completed for each facility at which studies are conducted.

2. Process Chart

The Process Chart (page 69) is the basic form for recording data on any sequence of operations. The symbols and the test used in the Process Chart are standard for forms of this type.

Some of the information from the Facility Questionnaire and the Process Chart are combined into a flow diagram, which can be drawn on the back of the Process Chart form. This diagram need not be as detailed as the customary flow diagrams; its main purpose is to indicate the number of obstacles the transporting vehicle must circumvent, the congestion it must

pass through, and the places where it picks up and releases its load.

3. <u>Work Sampling Observation Sheet I</u>

The Work Sampling Observation Sheet I (page 70) is used for recording data from the work sampling study. This form is designed for use on cycles such as the hook, tractor, or forklift cycle. Further information on the use of this form can be found in section VII, Work Sampling Technique.

4. <u>Work Sampling Observation Sheet II</u>

The Work Sampling Observation Sheet II (page 71) is similar to the Work Sampling Observation Sheet I, but it is designed primarily for use with the hold cycle. It can also be used for the shed cycle.

5. <u>Cycle Times</u>

The Cycle Times sheet (page 72) is designed to accommodate data so that the variation between cycle rates from hour to hour, day to day, and month to month, can be studied. This variation is to be studied by statistical techniques. The form is designed so that as many as three independent cycles can be studied simultaneously.

6. <u>Tally Sheet</u>

The Tally Sheet (page 73) is designed so that information on the rate of loading, tons/hour, can be obtained without depending on the checkers or clerks. The sheet is also designed so that a multitude of commodities in numerous hatches can be studied on the same sheet. The Tally Sheet, when used with the Process Chart, will give the loading rate.

7. <u>Time Study Sheet</u>

The Time Study Sheet (page 74) is a modification of a standard form used in conventional time-studies.

Name of Facility ______________________________

Operator ____________________ Date __________ By__________

Nature of facility (general description and/or sketch)

Elements

1. Range of tide ______________________________

2. Yearly weather ______________________________

Characteristics and dimensions of wharves

Wharf					
Type					
Length					
Width					
Apron width					
Net cargo area					
Berth	No.				
	Length				
Dock or slip dimensions					
Water depth					
No. of railroad tracks on apron					
Location of other trucks on wharf					

Characteristics and dimensions of transit sheds.

Facility ______________________

Transit shed					
Outside dimensions					
No. of decks					
Heights of decks					
Total area of decks					
Net usable area					
Net usable volume					
Max. floor load					
No. and location of doors					
Door dimensions					

Characteristics and dimensions of warehouses

Warehouse					
Stories					
Height/story					
Area/story					
Net usable area					
Net usable volume					
Max. floor loads					
Elevator capacities					

Characteristics and dimensions of outside storage areas

Area number					
Area (ft^2)					
Distance from apron					
Surface					

Supply Facilities | Facility ____________

Railroad

	Receiving or breakup yard	Dêparture or Classification yard	Car-Storage tracks
map, sketch or photo designation			
capacity (cars)			

Car working track.

Name	Platform Width	Length	Covered length

Truck-Loading and unloading facilities
Truck have access to:

Name	Platform width	Length	Covered length	Width of roadway	Width of turning areas

Description and use of handling equipment.

Facility__________ Berth__________ Loading/Unloading Obs.__________ Code No.__________

Commodity__________ Package__________ Sheet No.______ of______

Ship__________ Type__________ Hatch__________ Hold Position__________

Process Description (Indicate cycle divisions)	Chart Symbols	Men Req'd (No.)	Dist. Moved	Time Req'd (min.)	Equipment	Load Characteristics				Units per Load	Wt. per Load
						Shape	Length	Width	H't.		
	○ ○ △ □										
	○ ○ △ □										
	○ ○ △ □										
	○ ○ △ □										
	○ ○ △ □										
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	○ ○ △ □										
	○ ○ △ □										
	○ ○ △ □										
	○ ○ △ □										
	○ ○ △ □										
Summation					Unit Characteristics						

Code No.__________

Notes:

Holdmen:
Winchmen:
Hatchtender:

Frontmen:
Dockmen
Truck drivers:
Total:

WORK SAMPLING OBSERVATION SHEET I

Sheet No. ____________ of __________ Observer ______________ Code No. ________________

Hatch No. and Comm.								
Units/Load								
No. Trans. Agents								
Cycle / Time								
:00	54	42						
00	55	46						
01	57	47						
04	57	47						
04	59	50						
05	59	51						
06	:01	51						
07	02	52						
07	02	53						
08	03	55						
08	04	57						
09	05	59						
10	06	:01						
12	07	03						
15	08	03						
17	09	07						
20	10	08						
21	11	08						
24	12	10						
25	12	12						
26	13	13						
26	13	14						
29	15	15						
31	17	15						
33	19	17						
34	20	19						
34	20	20						
34	24	24						
35	25	25						
36	25	25						
37	26	26						
37	28	27						
38	29	28						
42	29	30						
43	32	30						
43	32	30						
44	36	34						
44	37	34						
50	38	35						
50	39	35						
52	40	35						
Σ	P	Q						
	L	O						
	R	G						
	E	S						
	D							
	A							
	U							
	C							
	X							
	Σ	Σ						
No. of Cycles								
Average Gross Cycle Time								

Code No.

June 1953

WORK SAMPLING OBSERVATION SHEET II

Sheet No.__________ of________ Observer__________________________ Code No. ____________________

Code No.

Hatch & Comm.		
Units/Load	No. Trans.Agents	
Cycle		

Time	Comm	Comm	D	A	U	C	X	Q	O	S
:00										
00										
01										
04										
04										
05										
05										
07										
07										
08										
08										
09										
10										
12										
15										
17										
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54										
55										
51										
51										
59										
59										
ΣP										
ΣL										
ΣR										
ΣE										
$\Sigma \%$										

Number of Cycles	
Avg. Gross Cycle Time	

Hatch & Comm.		
Units/Load	No. Trans. Agents	
Cycle		

Time	Comm	Comm	D	A	U	C	X	Q	O	S
:01										
02										
02										
03										
04										
05										
06										
07										
08										
09										
10										
11										
12										
12										
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51										
52										
53										
56										
57										
59										
ΣP										
ΣL										
ΣR										
ΣE										
$\Sigma \%$										

Number of Cycles	
Avg. Gross Cycle Time	

CYCLE TIMES

Sheet No.__________ of________ Observer______________ Code No.____________________

Code No.__________

Cycle			Cycle			Cycle		
Comm.			Comm.			Comm.		
Hatch			Hatch:			Hatch		
Cycle Time			Cycle Time			Cycle Time		
Start	Finish	Total	Start	Finish	Total	Start	Finish	Total

Notes:

TALLY SHEET

Sheet No. ______ of ______ Observer ____________________ Code No. ____________________

Code No. ______

MATCH AND COMMODITY

Start:	Start:	Start:	Start:
Finish:	Finish:	Finish:	Finish:
Units/Load:	Units/Load:	Units/Load:	Units/Load:
Code No:	Code No:	Code No:	Code No:
Total Time:	Total Time:	Total Time:	Total Time:
No. Units:	No. Units:	No. Units:	No. Units:
Time/Unit:	Time/Unit:	Time/Unit:	Time/Unit:
Start:	Start:	Start:	Start:
Finish:	Finish:	Finish:	Finish:
Units/Load:	Units/Load:	Units/Load:	Units/Load:
Code No:	Code No:	Code No:	Code No:
Total Time:	Total Time:	Total Time:	Total Time:
No. Units:	No. Units:	No. Units:	No. Units:
Time/Unit:	Time/Unit:	Time/Unit:	Time/Unit:
Start:	Start:	Start:	Start:
Finish:	Finish:	Finish:	Finish:
Units/Load:	Units/Load:	Units/Load:	Units/Load:
Code No.	Code No:	Code No:	Code No:
Total Time:	Total Time:	Total Time:	Total Time:
No. Units:	No. Units:	No. Units:	No. Units:
Time/Unit:	Time/Unit:	Time/Unit:	Time/Unit:

Facility ______________________ Commodity ______________________

Cycle ______________________ Order of cycle in operation ______________________

Units Handled Per Cycle ________

Code Number ________

No.	A	B	C	D	E	F	G	H	I	K	L	M	Interruptions No.	Remarks
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
													Sum	Date
													Number	Start
													Avg. time	End
													Sel. time	Obs. Time
													Rating	No. of units
													Norm. time	Observer

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